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Small Timber Harvesting Productivity and Cost: A Review of Some Recent Literature

by Charles H. Hawkins III

Rough Draft

Small Timber Harvesting Productivity and Cost: A Review of Some Recent Literature

for

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CONTENTS

ABSTRACT

INTRODUCTION

Study of Objectives

STUDY METHODS

RESULTS AND DISCUSSION

Information Sources and Types

Summarizing and Comparing Information

CONCLUSIONS AND RECOMMENDATIONS

Additional Literature Review and Summary

Cost Generalizations

A Procedural Approach

Summary

List of Tables:

Table 1.--Summary of current literature on small timber harvesting productivity and cost. (An illustrative example)

Table 2.--Summary of recent study results on small timber harvesting productivity and cost. (An example)

List of Figures:

Figure 1.--Identification codes to be used with tables 1 and 2.

Appendices:

APPENDIX A - Literature Review Notes

APPENDIX B - Bibliography for Future Review

Rough Draft

Small Timber Harvesting Productivity and Cost: A Review of Some Recent Literature

by Charles H. Hawkins III

ABSTRACT

Recent literature on small timber harvesting productivity and cost was reviewed. Notes are included on 76 research reports; 32 additional reports are listed. Proposals are made for tabular summary of study information, including comparison of productivity and cost results on a common basis. Additional literature review and summarization is recommended. Suggested is development of a procedure that enables the user to construct system costs for specific situations, or to make cost generalizations for a range of methods and conditions.

INTRODUCTION

A major problem throughout much of the Intermountain West is the management of small-diameter timber. In Idaho and Montana, about 30 billion cubic feet of wood is in trees 5.0 to 8.9 inches in diameter at breast height (dbh); lodgepole pine comprises the largest part of this resource (Host and Lowery 1983). Small-diameter trees occur as nonproductive components of oldgrowth stands, as well as in relatively young, overstocked stands (Mandzak, et. al. 1983). In recent years, researchers have focused on evaluating potential uses for small timber removed in precommercial thinnings and postharvest residue.

Concomitant research has studied the economics of harvesting small trees. Although high logging costs, low product values, poor demand, and fluctuating prices have historically made much of this small material marginally profitable or totally unmerchantable, new approaches have been investigated. Attempts have been made to quantify the costs of conventional harvest methods, as well as the costs of innovative techniques, modified equipment, and mechanized systems. Research efforts have concentrated on the economic relationships of small-wood production costs vis-a-vis total stand treatment cost and long-term demand.

This study is a logical consequence of previous investigations of harvesting feasibility in small-stem lodgepole pine in the Intermountain West (Hawkins 1987). It surveys selected literature which has been published on small timber harvesting productivity and cost; it also suggests how this information can be summarized in ways that will be useful to researchers, managers, and practitioners who must examine harvesting systems and costs more closely.

STUDY OBJECTIVES

This study was intended as a basis for further investigation. The objective was to review the literature pertinent to small timber harvesting productivity and cost, and to develop procedures for summarizing and comparing essential information from various sources. It was anticipated that generalized costs,

as well as a procedural approach to cost estimation, would subsequently be developed for small-diameter timber in the Intermountain West.

STUDY METHODS

More than 100 research reports were reviewed. These were found in trade magazines, professional journals, proceedings reports, and publications of research organizations. Each was scanned to ascertain whether it applied to small-diameter timber, contained useful production or cost data, or was of interest for any other reason. Because of current budget constraints, this review was not exhaustive.

Research reports which included relevant information were perused in greater detail. Important points about each study and it's presentation of results were recorded. The intent was to document the kinds of inquiries that have been made and the types of information that are available, rather than to summarize research results or conclusions. Generally, the reports selected for detailed review displayed production or cost data for component functions or elements of harvesting systems in relation to stand, treatment, or operating variables. Simulation models were avoided unless accompanied by useful basis data. A few reports were included solely as examples of how to aggregate information, or for the value of their bibliographies. Appendix A contains review notes on 76 reports. Appendix B is a bibliography of 32 additional reports which were not reviewed but may be pertinent.

These are in original note form and should be revised prior to publication.

Although the primary objective was to ascertain harvesting costs for subsawlog-size timber, it was necessary to review literature covering larger trees as well. The goal was to find sources based on actual collections of data in smaller size classes, rather than extrapolations from sawtimber studies. Relatively few studies focused strictly on subsawlog sizes, but many included small material along with larger trees.

Similarly, in spite of the primary objective to ascertain small timber harvesting costs for the Intermountain West, it was considered prudent to review literature covering all the United States and Canada. In this way, it was possible to survey a broader spectrum of emerging technology and changing concepts. A few Scandinavian sources were reviewed because of their obvious American applications. An extensive body of foreign literature was excluded, partly due to doubtful relevance, but largely because of budget limitations.

The time scope was also limited by both relevance and budget. Generally, only literature published during the past 10 years was reviewed. A few older studies were included for special reasons -- usually a noteworthy presentation of production results from conventional logging systems in smaller size classes. Overall, older study results were somewhat obviated by conceptual changes and technological advances.

Procedures for summarizing and comparing studies are presented as part of this preliminary investigation. An example of how the available literature can be summarized is given in table 1. This format tells the reader where to find literature pertaining to various stand conditions, treatments, or operations; it also describes the kinds of information presented. Table 2 is an example of how productivity and cost results from different studies can be compared on common bases. Figure 1 shows the codes used in tables 1 and 2. Time precludes more than illustrative examples of these summary and comparison formats.

This cursory search focused largely on stump-to-landing operations. A more thorough literature review would certainly yield additional data pertinent to in-woods processing and transportation.

RESULTS AND DISCUSSION

Information Sources and Types

Information on harvesting productivity and cost for subsawlog-size timber is generally found in literature covering larger trees as well. Studies often include stand treatments which require cutting a wide range of diameters regardless of merchantability. A frequent objective of such studies is to assess total and incremental stand treatment costs, as well as actual and potential product recovery values, when subsawlog-size trees are required to be harvested. Another common objective is the analysis of alternative harvesting systems, methods, and

equipment. But many studies are much more limited in scope, concentrating on specific makes of machinery or harvesting functions.

Cost and productivity information is presented in numerous forms and units of measure (Cubbage 1983). Trade magazines commonly report gross estimates based on average production per hour or per day. Such sources are good for comparing machines or systems, but do not provide useful data for production or cost analysis.

Research papers generally provide more precise information in tabular or graphical formats. Productivity or cost for different harvest functions or cycle elements is usually displayed to show the relative effects of stand, treatment, or operating variables. But such data must be critically reviewed to ascertain whether it is based on scientific sampling techniques, is statistically reliable, and is applicable beyond the local area.

The most reliable productivity and cost information is found in literature with tables, graphs, or other forms of data which have been developed from mathematical prediction equations based on accepted sampling techniques and statistical analysis.

Summarizing and Comparing Information

Several approaches have been used to summarize and compare information from harvesting productivity and cost studies. Cubbage (1983) classified 29 literature citations containing harvesting productivity information on southern pines; a tabular

summary was used to show the harvest functions, tree species, and types of data included in each article. Sarles and Luppold (1986) showed productivity and cost factors for six stump-to-landing systems based on operational data developed from 47 harvesting operations; tabular summaries compared stand conditions, treatments, production rates, and costs on common bases. The formats of tables 1 and 2 evolved largely from these sources.

Obviously, the myriad study objectives; the sundry stand conditions, treatment prescriptions, harvesting systems, and operating methods; the multiplicity of measurement units; and the diverse presentation of results complicate efforts to summarize and aggregate production and cost data. Two of the most important items that must be reduced to common denominators are differences in units of measure (e.g.: logs, trees, cubic feet, cords, tons, MBF; seconds, minutes, hours, days; person time, crew time, machine time, system time) and disparities between scheduled and productive time. Another critical concern in comparing or aggregating data from several sources is the inherent dissimilarity among study conditions and crew expertise: Many studies reflect or closely approximate actual production operations; while others are conducted in more artificial situations, often by inexperienced crews. A final major concern is the diversity of approaches to wages, machine rate computations, and allocation of service support and other overhead costs.

CONCLUSIONS AND RECOMMENDATIONS

As stated, this study was intended to provide a basis for further research. In spite of its limitations, this initial effort has revealed an extensive body of relevant literature, much of which will be useful for further analysis of small timber harvesting productivity and cost.

Additional Literature Review and Summary

A more exhaustive literature review is imperative in order to establish a solid foundation for developing generalized costs as well as a procedural approach to cost estimation. It is appropriate for future efforts to focus on studies reported during the past 10 years, with particular emphasis on (but not limited to) the Intermountain West.

Relevant literature should be reviewed for statistical reliability. Reports which meet this criteria should then be summarized in formats like tables 1 and 2. These aggregations would facilitate further comparison and analysis. Table 1 could be listed alphabetically; but table 2 would be more useful if grouped by harvesting systems or functions or both.

Cost Generalizations

The ability to make reasonable generalizations about small timber harvesting cost is important. Initial feasibility studies exploring possibilities for new products or new production facilities always ask broad questions such as, "How much will it cost to get the kind of wood I want?" A summary format like

table 2 will help to answer this question by showing some comparative costs for alternative harvesting systems or functions which produce different products under various conditions.

Generalizations about small timber harvesting cost can be presented as averages or ranges for stump-to-truck or stump-to-mill operations. These may represent a few typical combinations of stand, treatment, and operating variables; they might also be reduced further to represent overall averages for the anticipated range of operating variables. But to attempt this by amalgamating costs reported in diverse studies would be statistically indefensible. A better alternative is to use a procedural approach to estimate cost averages or ranges for representative situations.

A Procedural Approach

The ultimate goal is to develop a procedural approach for estimating the cost of harvesting small timber. The system will combine statistically reliable production information with computed operating costs. Good examples are provided by Cubbage (1981), Gardner (1982), Jackson, et. al. (1984), and Withycomb (1982 and 1981). Basic to this approach is the derivation of equations or mathematically generated tables which relate machine or system productivity to significant stand, treatment, and operating variables. The other important ingredient is a method for computing machine or system operating costs, along with illustrations for common machinery and systems. With this information,

the user can construct system costs for specific situations, or can make generalizations for a range of methods and conditions.

Summary

Completion of the literature review, tabular comparison of relevant study results, and development of a procedure for cost estimation will provide useful information for researchers, managers, and practitioners who must examine small timber harvesting systems and costs more closely.

Table 1.--Summary of current literature on small timber harvesting productivity and cost. (An illustrative example)

Author & Year	Pages	Tables	Figures	References	Prod. Data	Cost Data	Location	Major Species	Size Class	Terrain Class	Treatments	Operations	Products
Goetz (1987)	?	6	?	12	Yes	Yes	NR	NC	S,P	F,M,S	T	1,3,4	WT.
Goetz (1986)	138	13*	*	0	Yes	Yes	NR	NC	S,P	M,S	T	1,3,4, 5,6.	HF,FW, PP,PW.
Gonsior (1987)	?	5	17	3	Yes	No	NR	NC	S,P,ST	M,S	CC	2,3,6	L,PC.
Host (1983)	14	19	6	1	Yes	Yes	NR	NC	P	F	T	1,2,3, 5,6.	SL,HL, PP,HF, PC.
Keegan (1981)	9	6	0	0	No	Yes	NR						FW,HF, PC.
Koch (1985)	213	50	68	376	Yes	Yes	SO	SH	S,P,ST			1,2,3,4 5,6,7,8	SL,PW, FW,PC.
Lane (1981)	140	13	17	37*	Yes	Yes	SO	SP	SP		T	1,2,3 4,5,6	
Mandzak (1983)	17	10*	10	0	Yes	No	NR	NC	S,P,ST	F,M		2,3,6,7	SL,PC.
Maus (1986)	69	3*	*	0	Yes	No	NR	NC	S,P	F,M	T	1,2,3, 5,6.	HF,PP, FW,PW.

*Additional information unnumbered or in appendicies.

Table 2.--Summary of recent results on small timber harvesting productivity and cost.

									System Productivity		System Cost		
Author & Year	Location	Major Species	Size Class	Terrain Class	Treatments	Operations	Products	Crew Size	Stems/ Hour	Cu Ft/ Hour	Cost/ Hour	Cost/ Stem	Cost/ Cu Ft

SAMPLE FORMAT

Location:

NE- Northeast
NC- North Central
SE- Southeast
SO- South
SW- Southwest
NW- Northwest
NR- Northern Rockies
CR- Central Rockies
EC- Eastern Canada
WC- Western Canada
E- Europe

Species:

NC- Northern Conifers
SP- Southern Pines
NH- Northern Hardwoods
SH- Southern Hardwoods
OC- Other Conifers
OH- Other Hardwoods

Size:

S- Sapling (1 to 5" dbh)
P- Pole Timber (5 to 11"dbh)
ST- Saw Timber (11 to 21"dbh)

Terrain:

F- Flat (less than 10%)
M- Moderate (10% to 30%)
S- Steep (30% and over)

Operations:

1- Chainsaw felling, hand bunching.
2- Mechanized felling and bunching.
3- Ground skidding and forwarding.
4- Cable yarding, cable bunching.
5- Chainsaw delimbing, topping, and bucking; hand piling.
6- Mechanized delimbing, topping, and bucking; whole-tree chipping.
7- Loading.
8- Hauling.

Products:

SL- Sawlogs
HL- Houselogs
PP- Post and Poles
TL- Tree Lengths (delimbed and topped)
WT- Whole Trees (with limbs and tops)
PW- Pulpwood (bolts)
FW- Fuelwood (bolts)
HF- Hog Fuel
PC- Pulp Chips

Treatment:

T- Thinning
CC- Clearcut
PC- Partial Cut (regeneration)

Figure 1.--Identification codes to be used with tables 1 and 2.

Appendix A

APPENDIX A

Literature Review Notes

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Aird, Paul L.; P.L. Cottell; H.I. Winer; and C.J. Bredberg.
Year:	1970
Title:	Evaluating the productivity of logging machines: studies of Beloit Harvesters.
Source:	Pulp and Paper Magazine of Canada, September 18, 1970, p. 107-114, National Business Publications Ltd., Gardenvale, Quebec.
Pages:	8
Tables:	3
Figures:	6
References:	3
Prod. Data:	Yes
Cost Data:	No
Location:	Canada
Species:	
Size:	Mean volume per merchantable tree 1.2 to 6.5 cu. ft.
Terrain:	Mean slope 1 to 6%.
Treatments:	
Operations:	(02) Mechanical felling
Products:	
Remarks:	Evaluation of six Beloit Harvesters on three study sites. Objectives were to develop instruments, field methods, and analytical techniques for evaluating the productivity of new logging machines and systems. Study results are specific to Beloit Harvesters but have application to other machines and systems. Effects of important environmental and operating factors on productivity are discussed. Appendix provides regression equations.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Arola, Rodger A.
Year:	1983
Title:	Steep slope felling and bunching - the Menzi Muck.
Source:	Lynch, Dennis L., Coordinator and Editor. Proceedings -- Timber harvesting in the central Rockies: problems and opportunities; Jan. 4-6, 1983; Fort Collins, Colorado; p. 154-165; Publication No. XCM-87, Cooperative Extension Service, Colorado State University, Fort Collins, CO.
Pages:	12
Tables:	1
Figures:	5
References:	0
Prod. Data:	Yes
Cost Data:	No
Location:	Michigan
Species:	White birch, red maple, aspen
Size:	Dbh range 1 to 14 inches
Terrain:	Slope range 35 to 85%.
Treatments:	
Operations:	(02) Feller-buncher
Products:	Tree lengths
Remarks:	Describes the potential of the Menzi Muck (a semiwalking-type excavator) as a feller-buncher on steep slopes in the north central United States. The machine successfully felled and bunched both pole and sapling stands.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Arola, Rodger A.; and Edwin S. Miyata.
Year:	1981
Title:	Harvesting wood for energy.
Source:	USDA Forest Service, Research Paper NC-200, North Central Forest Experiment Station, St. Paul, Minn.
Pages:	25
Tables:	19
Figures:	18
References:	5
Prod. Data:	Yes
Cost Data:	Yes
Location:	Michigan
Species:	Northern hardwoods
Size:	Poletimber
Terrain:	Moderate
Treatments:	
Operations:	(02) Feller-bunchers, (03) Grapple skidders, (06) Chippers, (07) Loader, (08) Truck-tractor, chip vans.
Products:	Fuel chips

Remarks: Presents cost and productivity data for mechanized systems on five harvesting operations in northern hardwood poletimber. Equipment studied included the following:

Feller-bunchers: John Deere 544 loader with Rome shear and Drott 40 LC with and without accumulator.

Skidders: Clark Ranger 667 GS and John Deere 740 with grapples.

Delimber: Pettibone chain flail PM850.

Loader: Barko

Chippers: Trelan D-60 and Morbank 22-inch whole tree chippers.

Topwood Processor: Prototype with 12-inch shear.

Truck-tractors and chip vans as well as support equipment were included in the study.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Arola, Rodger A.; Edwin S. Miyata; John A. Sturos; and Helmuth M. Steinhilb.
Year:	1981
Title:	Felling and bunching small timber on steep slopes.
Source:	USDA Forest Service, Research Paper NC-203, North Central Forest Experiment Station, St. Paul, Minn.
Pages:	12
Tables:	4
Figures:	6
References:	4
Prod. Data:	Yes
Cost Data:	Yes
Location:	Michigan
Species:	White birch, red maple, white pine, aspen.
Size:	Dbh range 4 to 14 inches.
Terrain:	Slope range 35 to 85%.
Treatments:	
Operations:	(02) Feller-buncher
Products:	Tree lengths

Remarks: This publication presents preliminary results on the operation and performance of the Menzi Muck (a semiwalking-type excavator) as a small-tree, steep terrain feller-buncher. Analysis of delay time and elemental time per cycle is summarized for studies in pole and sapling stands. Comparisons are shown between single tree shearing versus a shear with a tree accumulating feature.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Arvidsson, Alf; and Michael Spahr.
Year:	1980
Title:	The Makeri thinning system - an evaluation of the Makeri harvester and Makeri forwarder in thinning.
Source:	Institution for Skogsteknik, Stencil nr 105, College of Forestry, Dept. of Operational Efficiency, Garpenberg, Sweeden.
Pages:	54, plus appendices
Tables:	2, plus text and appendices
Figures:	13
References:	108
Prod. Data:	Yes
Cost Data:	Yes
Location:	Sweeden
Species:	Pine, spruce
Size:	Dbh range 2 to 13 inches
Terrain:	Average slope 7%.
Treatments:	Thinning
Operations:	(02) Feller-buncher; (03) Forwarder/bunk skidder; (06) Mechanical delimber and bucker.
Products:	3-meter (9.75-ft.) pulpwood bolts.

Remarks: This report gives the results of a evaluation of a test of the Makeri system (harvester and forwarder) in thinning. The evaluation is based on an analysis of attained production, calculated costs, and damages measured in the residual stand. Also included are measurement of the yarding road width and an analysis of thinning removal. An ergonomic evaluation of the machine is contained in the appendix.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Barger, Roland L.; and Robert E. Benson.
Year:	1981
Title:	Intensive utilization with conventional harvesting systems.
Source:	Proceedings -- Harvesting and utilization opportunities for forest residues in the Northern Rocky Mountains; Nov. 28-30, 1979; p. 77 - 95; USDA Forest Service, General Technical Report INT-110, Intermountain Forest and Range Experiment Station, Ogden, UT.
Pages:	19
Tables:	12
Figures:	5
References:	0
Prod. Data:	Yes
Cost Data:	Yes
Location:	Montana, Wyoming
Species:	Western Larch, Douglas-fir, Lodgepole pine.
Size:	
Terrain:	Gentle and steep
Treatments:	Clearcut, partial cut
Operations:	(01) Chainsaw felling, hand bunching; (02) Feller-bunchers; (03) Crawler skidders; (04) Skyline yarders; (05) Chainsaw delimbing, topping, bucking; (06) Mechanical delimbing and bucking, whole-tree chipping.
Products:	Logs, tree lengths, whole trees, chips.
Remarks:	Forest residues utilization research included case studies of the efficiency of existing harvesting systems in achieving close fiber utilization. Treatment specifications included an array of silvicultural systems, cutting specifications, utilization standards, and harvest systems at each of three diverse study sites. Field evaluations included the use of in-woods chipping systems on gentle terrain, crawler skidder systems on gentle terrain, and skyline systems on steep terrain. In each situation, utilization standards ranged from conventional saw log utilization to near-total utilization of available fiber. Intensive utilization was achieved concurrent with saw log harvesting, rather than through postharvest salvage. The total costs of harvesting merchantable material and residue together were partitioned to derive costs of residue recovery.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Baumgras, John E.; and Penn A. Peters
Year: 1985
Title: Cost and production analysis of the Bitterroot Miniyarder on an Appalachian hardwood site.
Source: USDA Forest Service, Research Paper NE-557, Northeastern Forest Experiment Station, Broomall, Pa.

Pages: 13
Tables: 3
Figures: 7
References: 10
Prod. Data: Yes
Cost Data: Yes
Location: Virginia
Species: Chestnut oak, scarlet oak.
Size: Average dbh 7.7 inches; range 4 to 12+ inches; 90% smaller than 10 inches.
Terrain: Slope range 15 to 40%.
Treatments:
Operations: (04) Cable yarding
Products: Fuelwood

Remarks: The Bitterroot Miniyarder (a small, mobile, inexpensive cable yarder designed to log small trees on steep slopes) was studied to determine production rates and costs and to identify those factors affecting yarding cost. The yarder was rigged in a live skyline configuration with a Christy carriage. A small crawler tractor was used for decking and landing maintenance, but was not included in the time or the cost analysis. Linear regression methods were used to determine the functional relationships between site factors and yarding cycle time, and yarding element times. Equations were developed for predicting cycle time and production for significant variables.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Biltonen, Frank E.; William A. Hillstrom, Helmuth M. Steinhilb; and Richard M. Godman.
Year:	1976
Title:	Mechanized thinning of northern hardwood pole stands: methods and economics.
Source:	USDA Forest Service, Research Paper NC-137, North Central Forest Experiment Station, St. Paul, Minn.
Pages:	17
Tables:	14
Figures:	10
References:	15
Prod. Data:	Yes
Cost Data:	Yes
Location:	Michigan
Species:	Northern hardwoods
Size:	Dbh range 5 to 20 inches
Terrain:	Flat
Treatments:	Thinning
Operations:	(01) Chainsaw felling, (02) Feller-buncher with and without accumulator, (03) Grapple skidder, (06) Chipper, (07) Loader, (08) Truck tractors, chip vans.
Products:	Chips, sawlogs

Remarks: An analysis of the cost of thinning, chipping, and transporting second-growth northern hardwood pole stands using a completely mechanized system.

Equipment included a John Deere 544 feller-buncher with Rome accumulator shear, Clark Ranger 667 grapple skidder, Trelan D-60 whole tree chipper, and Barko loader. Costs are also given for transportation and support equipment.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Boyd, Jack; and Wayne Novak.
Year:	1977
Title:	Estimate wood cost, productivity and investment needs for 84 logging system combinations.
Source:	Pulp & Paper Canada, Vol. 78, No. 5, May 1977, p. 69-78.*
Pages:	10
Tables:	3
Figures:	4
References:	0
Prod. Data:	Yes
Cost Data:	Yes
Location:	Canada
Species:	
Size:	
Terrain:	
Treatments:	
Operations:	(01) Chainsaws, (02) Feller-bunchers, (03) Skidders and forwarders, (05) Chainsaw delimbing, bucking, and topping, (06) Mechanical processing.
Products:	Tree lengths, full trees, short wood.
Remarks:	Presents a method of comparing logging system and machine concepts. Compares industry average production rates and costs with industry minimum and ultimate performance for 84 logging system combinations.

* This paper -- W.S. 1 No. 2723 (B-4-e): ODC 311 -- was presented at the 58th Annual Meeting of the Woodlands Section , CPPA, held March 28-30, 1977, in Montreal, Que.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Brock, Samuel M.; Kenneth D. Jones; and Gary W. Miller.
Year:	1986
Title:	Felling and skidding costs associated with thinning a commercial hardwood stand in northern West Virginia.
Source:	Northern Journal of Applied Forestry, December 1986, p. 159-163.
Pages:	5
Tables:	6
Figures:	2
References:	7
Prod. Data:	Yes
Cost Data:	Yes
Location:	West Virginia
Species:	Yellow-poplar, red oak.
Size:	
Terrain:	
Treatments:	Thinning
Operations:	(01) Chainsaw felling, (03) Rubber-tired skidder, (05) Chainsaw delimbing, topping, and bucking.
Products:	Sawlogs

Remarks: Three thinning treatments were applied in a 50-year-old mixed oak, cove hardwood stand in northern West Virginia. A commercial logging contractor using chainsaws and a rubber-tired skidder (John Deere 540B) conducted the operations. Time-study data were used to compute production rates for felling marked trees and skidding tree-length trees to roadside landings for each thinning treatment. Regression equations for predicting felling and skidding times were developed for each treatment. Data from these equations can be used in estimating production rates and costs for similar thinning operations. A nomogram is provided for estimating felling and skidding costs for a 60% residual stocking treatment, the current recommended silvicultural prescription for stands similar to the study area.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Burrows, James O.; Eldon D. Olsen; and Loren D. Kellogg.
Year:	1986
Title:	Swinging and processing whole trees in a Douglas-fir thinning.
Source:	Transactions of the American Society of Agricultural Engineers, Vol. 29 (1): January - February, 1986, p. 31-33.
Pages:	3
Tables:	3
Figures:	0
References:	7
Prod. Data:	Yes
Cost Data:	Yes
Location:	Oregon
Species:	Douglas-fir, grand fir.
Size:	
Terrain:	
Treatments:	Thinning
Operations:	(010) Chainsaw felling, (03) Rubber-tired skidder swinging, (04) Skyline yarding (05) Chainsaw delimbing and bucking, (07) Hydraulic loader.
Products:	Sawlogs
Remarks:	Procedures, crew size, and machines suitable for swinging and processing whole-tree Douglas-fir during cable thinning were evaluated in a time and productivity study. Chainsaw delimbing and bucking productivity performed at the stump and the roadside was compared. A rubber-tired cable skidder and hydraulic knuckleboom loader were compared for efficiency in swinging logs.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Csizmazia, J.; and J. A. McIntosh.
Year:	1964
Title:	Logging small trees in Alberta
Source:	British Columbia Lumberman, November 1964.
Pages:	5
Tables:	7
Figures:	2
References:	6
Prod. Data:	Yes
Cost Data:	Yes
Location:	Alberta
Species:	White spruce, lodgepole pine
Size:	Dbh range 7 to 16 inches.
Terrain:	
Treatments:	
Operations:	(01) Chainsaw felling, (03) Crawler-tractor bunching, arch-truck skidding, (05) Chainsaw delimbing and bucking.
Products:	Sawlogs
Remarks:	Analyzes production and cost of felling, bunching, and skidding to portable sawmills on five operations. Considers the effects of tree size, turn volume, bunching distance, and tree-lengths vs. log-length methods. Reports average productivity for combined operations by phase of operation and dbh classes.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Cubbage
Year: 1983
Title: Harvesting productivity information for southern pines.
Source: Southern Journal of Applied Forestry, Vol. 7, No. 3, August 1983, p. 128-134, Society of American Foresters, Bethesda, Md.

Pages: 7
Tables: 2
Figures: 0
References: 53
Prod. Data: No
Cost Data: No
Location:
Species: Southern pines
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks: Studies estimating production rates for harvesting southern pines are reviewed and summarized. Types of harvesting productivity information, limitations, and applications are discussed. Southern pine harvesting studies are classified by harvest function, tree species, data type, and harvest type. Other sources of harvesting productivity are described.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Cubbage, Frederick W.
Year:	1981
Title:	Machine rate calculations and productivity rate tables for harvesting southern pine.
Source:	Staff Paper Series 24, Department of Forest Resources, College of Forestry and the Agricultural Experiment Station; Institiute of Agriculture, Forestry, and Home Economics; University of Minnesota, St. Paul, Minn.
Pages:	16, plus appendicies
Tables:	5, plus appendicies
Figures:	0
References:	25
Prod. Data:	Yes
Cost Data:	Yes
Location:	South
Species:	Southern pines
Size:	Dbh range 3 through 20 inches
Terrain:	
Treatments:	
Operations:	(01) Chainsaw felling, hand piling; (02) Rubber-tired and tracked feller-bunchers with and without accumulators,; (03) Tree shears, rubber-tired and tracked skidders with and without grapples, short-wood forwarders; (05) Chainsaw delimbing, topping, and bucking; (06) Slasher, iron gate delimber, mechanical delimber, whole-tree chipper.; (07) Cable and hydraulic loaders; (08) Log trucks, chip vans,lowboy trailer.
Products:	Sawlogs, pulpwood, tree lengths, chips.
Remarks:	Complete 1980 costs are summarized for all types of harvesting equipment common in the South. Published information on productivity rates for equipment used in southern pines is reviewed and summarized in tabular form. Data sources and assumptions used in the machine rate calculations and productivity tables are summarized in the text. Appendix A shows machine rate calculations for 38 classifications of equipment. Appendix B presents tables of productivity rates by diameter class or skidding/forwarding distance or both for 63 harvest operation and machine classifications. All production rates are shown in cubic feet per productive hour. Data sources and original units of measurement are given for each productivity rate table; underlying equations are given when available.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Forest Engineering, Inc.
Year:	1981
Title:	Development of harvesting alternatives: analysis procedures.
Source:	USDA Forest Service, Research Project FS-INT-3251-101, 102A; A report submitted to Intermountain Forest and Range Experiment Station, Ogden, UT
Pages:	
Tables:	
Figures:	
References:	Bibliography
Prod. Data:	
Cost Data:	
Location:	
Species:	
Size:	
Terrain:	
Treatments:	
Operations:	
Products:	
Remarks:	Extensive bibliography of pre-1980 literature.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Gardner, Rulon B.
Year:	1982
Title:	Estimating production rates and operating costs of timber harvesting equipment in the northern Rockies.
Source:	USDA Forest Service, General Techincal Report INT-118, Intermountain Forest and Range Experiment Station, Ogden, UT.
Pages:	29
Tables:	9
Figures:	23
References:	123
Prod. Data:	Yes
Cost Data:	Yes
Location:	Northern Rocky Mountains
Species:	
Size:	Sawlog
Terrain:	
Treatments:	
Operations:	(02) Feller-bunchers, (03) Tracked and rubber-tired skidders, (04) Jammers, high-lead yarders, skyline yarders, balloon yarders, (06) Mechanical delimbing, mobile chipper, (07) Heel-boom, knuckle-boom, long-boom, and front-end loaders.
Products:	Sawlogs
Remarks:	A summary of studies completed in the preceding decade (1972 to 1981). Provides descriptions of equipment and logging methods, and equations, nomographs, tables, and production data for estimating system productivity. Methods for designing systems, computing costs, and estimating fuel requirements are also included.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Gibson, David F.; William R. Taylor; and Michael J. Gonsior.
Year: 1984
Title: Bunching timber with a radio-controlled winch in mountainous terrain.
Source: Transactions of the American Society of Agricultural Engineers, Vol. 27, No. 5, p. 1270-1276, 1984. American Society of Agricultural Engineers, St. Joseph, Michigan.

Pages: 7
Tables: 4
Figures: 7
References: 2
Prod. Data: Yes
Cost Data: Yes
Location: Montana
Species: Lodgepole pine
Size: Sawlog
Terrain: Slopes generally less than 40%.
Treatments:
Operations: (04) Cable bunching
Products: Tree-length sawlogs

Remarks: A study was conducted to test the feasibility of using a small radio-controlled winch (Kolpe Radio-Tir 740) to bunch timber into loads prior to yarding, specifically with the Helistat heavy-lift airship. Several operating methods and decking patterns were specified for winch testing. Production and cost results are displayed for eight test cells along with relative indications of variables such as slope, site conditions, systems, and methods. It should be noted that the logging crews employed were U.S. Forest Service seasonal employees with little or no logging experience. Results must be tempered with a good measure of judgment.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Gibson, H. G.; P. E. Pope; D. L. Cassens; B. C. Fischer; and G. M. Wright.
Year:	1983
Title:	Thinning the upland hardwood forest: a mechanized system.
Source:	Jones, Earle P. Jr., Editor. Proceedings -- Second biennial southern silvicultural research conference, November 4-5, 1982, Atlanta, Georgia; USDA Forest Service, General Technical Report SE-24, p. 230-239, Southeastern Forest Experiment Station, Asheville, NC.
Pages:	10
Tables:	10
Figures:	6
References:	10
Prod. Data:	Yes
Cost Data:	Yes
Location:	Southeast
Species:	Oak-hickory: oak, hickory, maple, ash, sassafras.
Size:	Dbh range 4 to 12 inches
Terrain:	Slope 6 to 12%.
Treatments:	Thinning
Operations:	(02) Feller-buncher, (03) Grapple skidder, (06) Chipper
Products:	Chips
Remarks:	This paper reports on the costs and productivity of various machines combined to produce a low capital cost but highly mechanized system for thinning upland hardwoods for energy biomass or pulp chips. The system was composed of a Melroe Bobcat Model 1080 feller-buncher with 18-inch shear, a Dunham Model 660 75.5 hp skidder with 40-inch grapple, and a Morbark Model 12 whole-tree chipper with 12-inch throat. Chips were transported by highway chip vans.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Goetz, Henry L.
Year:	1987
Title:	Productivity of alternative harvesting systems in small timber.
Source:	Barger, Roland L., Compiler. Proceedings -- workshop on management of small-stem lodgepole pine; June 30 - July 2, 1986; Fairmont Hot Springs, MT. USDA Forest Service, General Technical Report, Intermountain Research Station, Ogden, UT.
Pages:	?
Tables:	6
Figures:	?
References:	12
Prod. Data:	Yes
Cost Data:	Yes
Location:	Montana
Species:	Western larch, ponderosa pine, lodgepole pine.
Size:	Average volume per stem range 0.7 to 8.3 cubic feet.
Terrain:	Gentle and steep
Treatments:	Thinning
Operations:	(01) Chainsaw felling, hand bunching; (03) Farm tractor w/grapple skidding and forwarding; (04) Radio-controlled bunching winch, skyline yarders.
Products:	Whole trees.
Remarks:	Reports on development and tests of full-tree thinning systems. Studies are more fully described in Goetz (1986), Maus (1986), and Goetz (1983). Stand conditions, system descriptions, production rates, and costs are presented in the text as well as in tabular summaries.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Goetz, H. L.; and F. J. Maus.
Year:	1986
Title:	Thinning on steep slopes with low-cost cable yarders.
Source:	Montana Forest and Conservation Experiment Station, University of Montana, Missoula, MT.
Pages:	138, appendices and glossary
Tables:	13, plus numerous in appendices.
Figures:	numerous un-numbered in text.
References:	0
Prod. Data:	Yes
Cost Data:	Yes
Location:	Montana
Species:	Ponderosa pine, lodgepole pine, western larch.
Size:	Average stem size range 0.9 to 8.3 cubic feet.
Terrain:	Average slope range 25 to 45%.
Treatments:	Thinning
Operations:	(01) Hand felling and bunching; (03) Farm tractor and rubber-tired skidder swinging; (04) Cable yarding; (05) Chainsaw delimbing, topping, bucking; (06) Whole-tree chipping.
Products:	Hog fuel, firewood, posts, poles, rails, pulpwood.
Remarks:	This project investigated, demonstrated, and analyzed three low-cost cable yarding systems suitable for removing full trees from forest thinning operations on steep terrain. These included a cable winch that attached to a farm tractor, the Bitterroot Miniyarder, and the Clearwater Yarder. Studies were conducted on six units representing a variety of timber types and stand conditions. Associated activities such as felling, bunching, swinging, and processing were included in the analysis. Stand conditions, system descriptions, products, production rates, costs, and revenues are presented in tabular form. The text and appendices contain detailed analyses, equipment specifications, and selected photographs of operations. (Also see Goetz 1987.)

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Goetz, Henry; and John R. Host.
Year:	1983
Title:	Bunching and swinging alternatives for small-stem timber.
Source:	Final Draft // Progress Report, Study No. 3251-202-4, Cooperative Agreement 22-C-2-INT-118, Intermountain Forest and Range Experiment Station, Ogden, UT.
Pages:	18
Tables:	3
Figures:	0
References:	0
Prod. Data:	Yes
Cost Data:	Yes
Location:	Montana
Species:	Douglas-fir, ponderosa pine.
Size:	Saplings, poles, small sawlog; average volume per stem range 0.44 to 8.97 cubic feet.
Terrain:	Slope range 0 to 45%
Treatments:	Thinning
Operations:	(01) Chainsaw felling, hand bunching; (03) Farm tractor forwarding; (04) Radio-controlled bunching winch, skyline yarder; (05) Chainsaw delimbing and topping; (06) Whole-tree chipper.
Products:	Tree lengths, whole trees.
Remarks:	The principal purpose of this study was to test the Kolpe Radio Tir sled-mounted winch as a buncher in precommercial thinning situations in Western Montana. A small live skyline yarder, designed and built by the Forest Service, was also given a limited field test as a potential steep-slope alternative. A four-wheel drive John Deere Model 2940 farm tractor with a heeling grapple was used as a forwarder.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Gonsior, Michael J.; and John M. Mandzak.
Year:	1987
Title:	Mechanized systems for harvesting small trees in mountainous terrain.
Source:	Barger, Roland L., Compiler. Proceedings -- workshop on management of small-stem lodgepole pine; June 30 - July 2, 1986; Fairmont Hot Springs, MT. USDA Forest Service, General Technical Report, Intermountain Research Station, Ogden, UT.
Pages:	?
Tables:	5
Figures:	17
References:	3
Prod. Data:	Yes
Cost Data:	No
Location:	Montana
Species:	Lodgepole pine, western larch, Douglas-fir.
Size:	Average dbh 6 inches; primary range 4 to 10 inches.
Terrain:	Slope range 10 to 30%.
Treatments:	Clearcut, seed tree.
Operations:	(02) Feller-buncher; (03) Grapple skidder; (06) Mechanical delimber, whole-tree chipper.
Products:	Sawlogs, chips.
Remarks:	The Timbco feller-buncher was evaluated as part of a mechanized multi-product harvesting system for steep terrain. Results of this investigation pertain especially to small-stem lodgepole pine stands. In addition to information on the Timbco, results from associated studies of mechanized delimbing, debarking, and chipping are also provided. The text, tables, and figures provide detailed analysis of performance and effects of stand and terrain conditions.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Gonsior, M. J.; and L. R. Johnson.
Year:	1985
Title:	Harvesting systems for lodgepole pine forests.
Source:	Baumgartner, David M.; Richard G. Krebill; James T. Arnott; and Gordon F. Weetman; Compilers and Editors. Proceedings -- Lodgepole pine: the species and its management; May 8-10, 1984, Spokane, WA; May 14-16, 1984, Vancouver, B.C.; p. 317-323; Cooperative Extension, 202 Van Doren Hall, Washington State University, Pullman, WA
Pages:	7
Tables:	0
Figures:	3
References:	24
Prod. Data:	No
Cost Data:	No
Location:	
Species:	Lodgepole pine
Size:	
Terrain:	
Treatments:	
Operations:	
Products:	

Remarks: A good source of additional references.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Granskog, James E.; and Walter C. Anderson.
Year:	1981
Title:	Dense undergrowth reduces feller-buncher productivity in shortleaf pine plantations.
Source:	USDA Forest Service, Research Note SO-274, Southern Forest Experiment Station, New Orleans, La.
Pages:	4
Tables:	1
Figures:	3
References:	1
Prod. Data:	Yes
Cost Data:	No
Location:	Tennessee
Species:	Shortleaf pine (plantation)
Size:	
Terrain:	
Treatments:	Thinning
Operations:	(02) Feller-buncher
Products:	
Remarks:	Production rates of a Melroe Bobcat 1075 feller-buncher are shown for row thinning pine plantations with light and dense undergrowth conditions. Dense undergrowth reduced machine output by about 20 percent.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Granskog, James E.
Year:	1978
Title:	Harvesting costs for mechanized thinning systems in slash pile plantations.
Source:	USDA Forest Service, Research Paper SO-141, Southern Forest Experiment Station, New Orleans, La.
Pages:	7
Tables:	4
Figures:	0
References:	2
Prod. Data:	Yes
Cost Data:	Yes
Location:	South
Species:	Slash pine
Size:	
Terrain:	
Treatments:	Thinning
Operations:	(02) Feller-bunchers; (03) Grapple skidder; forwarder; (05) Chainsaw delimbing, topping, bucking; (06) Mechanical delimbing, topping, bucking; (07) Loader; (08) Trucks.
Products:	Pulpwood
Remarks:	This report estimates harvesting costs for four tree harvester systems designed to row thin slash pine plantations. These estimates can be used to compare systems or to determine economical thinning opportunities for a given system. The productivity of shortwood, tree-length, and whole tree harvesters is summarized for selected stand conditions, as are output per man-day and system costs.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Hannula, O.
Year:	1971
Title:	The effect of average stand diameter on tree-length logging costs.
Source:	Pulp and Paper Magazine Canada, Vol. 72, No. 2, February, 1971, p. 96-100.
Pages:	5
Tables:	2
Figures:	8
References:	0
Prod. Data:	Yes
Cost Data:	Yes
Location:	Alberta
Species:	Black-spruce, white spruce, lodgepole pine.
Size:	Butt diameter range 6 to 16 inches.
Terrain:	
Treatments:	Clearcut
Operations:	(01) Chainsaw felling, (03) Rubber-tire skidder.
Products:	Tree lengths

Remarks: Reports on data collection, statistical analysis, and deductions from the results of a 1968 study. Graphs and tables show productivity and cost by butt diameter classes for a 2-man crew. Also graphs profit relationships of various stand sizes for tree-length wood skidded to roadside. Study involved clearcutting of 32,000 cords of pulpwood in virgin stands. This report illustrates how to determine marginal stands by use of the break-even method.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Hawkins, Charles H. III
Year:	1987
Title:	Timber harvesting feasibility in small-stem lodgepole pine.
Source:	Barger, Roland L., Compiler. Proceedings -- workshop on management of small-stem lodgepole pine; June 30 - July 2, 1986; Fairmont Hot Springs, MT. USDA Forest Service, General Techinical Report INT-, Intermountain Research Station, Ogden, UT.
Pages:	18
Tables:	15
Figures:	7
References:	2
Prod. Data:	Yes
Cost Data:	Yes
Location:	Montana, Utah
Species:	Lodgepole pine
Size:	Average dbh range 1.71 to 4.97 inches.
Terrain:	Average slope range 2 to 30%
Treatments:	Thinning, clearcuts
Operations:	(01) Chainsaw felling, hand bunching; (02) Tree shear; (03) Hand skidding, tractor winching, forwarding with rubber-tired and tracked skidders and farm tractors; (05) Chainsaw delimbing, topping, and bucking, handpiling; (07) Hand loading.
Products:	Posts and poles, sawlogs, houselogs.
Remarks:	This study was designed to evaluate opportunities for cost reduction and revenue generation in harvesting small-stem lodgepole pine. Operations on 11 study units (including 25 treatment subunits) were assessed for productivity, cost, and product recovery. Harvesting systems included a variety of product-length and tree-length methods; these were labor-intensive operations using chainsaws and manual labor, as well as small farm tractors, crawlers, and rubber-tired skidders. Tabular summaries compare stand conditions, treatments, productivity, incremental costs, and product recovery. In addition to actual product recovery, predictions of potential product value were made using a methodology developed in a concurrent study (see Hawkins and Schlieter, this proceedings). The influence of stand, treatment, and harvesting variables were analyzed statistically as well as subjectively. It is important to note that stand treatments were specified to meet multidisciplinary research objectives and were quite demanding and restrictive for the operators.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Host, John R.; and David P. Lowery.
Year:	1983
Title:	Salvage and thinning operations in second-growth ponderosa pine stands.
Source:	USDA Forest Service, Research Paper INT-311, Intermountain Forest and Range Experiment Station, Ogden, UT.
Pages:	14
Tables:	19
Figures:	6
References:	1
Prod. Data:	Yes
Cost Data:	Yes
Location:	Montana
Species:	Ponderosa pine
Size:	Average dbh range 8 to 10 inches
Terrain:	Average slopes less than 10%.
Treatments:	Thinning
Operations:	(01) Chainsaw felling; (02) Feller-buncher; (03) Farm tractors and skidders with and with out grapples; (05) Chainsaw delimbing, topping, bucking; (06) Whole-tree chipping.
Products:	Sawlogs, houselogs, posts, hog fuel, pulp chips.
Remarks:	This report describes and discusses a harvesting system made up of commercially available equipment and modified farm tractors that has been successfully used to salvage and thin second-growth ponderosa pine stands. Commercial equipment consisted of feller-bunchers, a skidder, and a chipper. Farm tractors were equipped with grapples and metal reinforcements to adapt them to forest use. Two studies (including 12 units) made in the same general area are described, as well as procedures for recovering multiple products.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Host, John R.
Year:	1981
Title:	Low capital investment logging systems.
Source:	Proceedings -- Harvesting and utilization opportunities for forest residues in the Northern Rocky Mountains; Nov. 28-30, 1979, p. 97-111; USDA Forest Service, General Techincal Report INT-110, Intermountain Forest and Range Experiment Station, Ogden, UT.
Pages:	15
Tables:	5
Figures:	6
References:	4
Prod. Data:	Yes
Cost Data:	Yes
Location:	
Species:	
Size:	Average volume per piece range 4.23 to 25.60 cubic feet.
Terrain:	
Treatments:	
Operations:	(03) Horses, farm tractors, tracked and rubber-tired skidders with and without grapples; (04) skyline yarders, converted shovels.
Products:	Logs
Remarks:	This report deals with the impact of capital investment on logging productivity and costs. Ten ground skidders and 15 cable yarders were studied. Equipment studied is identified and described, along with discussions of factors affecting productivity and cost.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Host, John; and Joyce Schlieter.
Year:	1978
Title:	Low cost harvesting systems for intensive utlization in small-stem lodgepole pine stands.
Source:	USDA Forest Service, Research Paper INT-201, Intermountain Forest and Range Experiment Station, Ogden, UT.
Pages:	20
Tables:	10
Figures:	5
References:	0
Prod. Data:	Yes
Cost Data:	Yes
Location:	Montana
Species:	Lodgepole pine
Size:	Dbh range 5.5 to 9.5 inches.
Terrain:	Slopes 20 to 45%
Treatments:	
Operations:	(03) Rubber-tired skidder, horse, crawler tractor.
Products:	Studlogs, houselogs, fence posts.

Remarks: Three skidding methods -- small rubber-tired skidder, horse, and farm crawler tractor -- were compared in an overmature lodgepole pine stand. The rubber-tired skidder was a Garrett Tree Farmer Model 15; the crawler tractor was a 25 hp John Deere Model 420. Five comparable units were logged using two different utilization standards -- loggers' choice and 2.5-inch top d.i.b. Skidding production, product volume removed per acre, and residue volume per acre are compared for each cutting unit. Skidding costs, in order of increasing costs were rubber-tired skidder, horse, and crawler tractor. On a capital investment basis, horse skidding is the most efficient.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Ince, Peter J.; John W. Henley; John B. Grantham; and Douglas L. Hunt.
Year:	1984
Title:	Costs of harvesting beetle-killed lodgepole pine in eastern Oregon.
Source:	USDA Forest Service, General Technical Report PNW-165, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.
Pages:	26
Tables:	15
Figures:	0
References:	0
Prod. Data:	Yes
Cost Data:	Yes
Location:	Oregon
Species:	Lodgepole pine
Size:	Average dbh range 6.3 to 10.0 inches.
Terrain:	
Treatments:	
Operations:	(02) Feller-bunchers; (03) Grapple skidders; (06) Mobil chipper, log trimmer; (07) Log loader; (08) Log trucks, chip vans.
Products:	Sawlogs, houselogs, chips.
Remarks:	Mechanized harvest operations were conducted on six study sites totalling 134 acres. Time required for equipment, labor, and administration is summarized for each machine classification on each harvest unit. Harvest costs are also summarized by machine classification for each unit. Harvest costs are prorated to logs and chips by percent weight. Transportation costs and total delivered costs of logs and chips are shown in various units of production for each unit. Energy requirements are analyzed.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Ince, Peter J.
Year:	1982
Title:	Economic perspective on harvesting and physical constraints on using small, dead lodgepole pine.
Source:	Forest Products Journal, Vol. 32, No. 11/12, November/December 1982, p. 61-66, Forest Products Research Society, Madison, Wis.
Pages:	7
Tables:	2
Figures:	3
References:	11
Prod. Data:	No
Cost Data:	Yes
Location:	Oregon
Species:	Lodgepole pine
Size:	Mean large-end diameter 8 inches.
Terrain:	
Treatments:	
Operations:	(02) Feller-bunchers, (03) Grapple skidders, (06) Mobile chipper, mobile log trimmer, (07) Log handling, (08) Log trucks and chip vans.
Products:	Sawlogs, fuel chips.
Remarks:	Research includes a case study on six harvest sites. Relationships of roundwood and chip production, markets, energy inputs, and cost-to-energy-value ratio are evaluated.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Jackson, Timothy P.; Richard P. Withycomb; and Charles E. Keegan III.
Year:	1984
Title:	Estimating the costs of recovering forest residue in the Northern Rocky Mountains.
Source:	Bureau of Business and Economic Research, University of Montana, Missoula, MT, in cooperation with Intermountain Forest and Range Experiment Station, Ogden, UT.
Pages:	18, plus appendicies
Tables:	12
Figures:	5
References:	63
Prod. Data:	Yes
Cost Data:	Yes
Location:	Northern Rockies
Species:	
Size:	Dbh range 4 to 28 inches; range of volume per piece 0.5 to 100.0 cubic feet.
Terrain:	
Treatments:	
Operations:	(01) Chainsaw felling; (02) Mechanical felling; (03) Tracked and rubber-tired skidders with and without grapplers; (04) Cable yarding; (05) Chainsaw delimbing; (06) Mechanical delimbing, chipping; (07) Loading; (08) Hauling.
Products:	Tree-lengths, whole trees, chips.
Remarks:	A cost model was developed to deal with recovery of nonsawtimber residue and material cut in timber stand improvements. Cost tables were developed from averages covering a broad range of operating conditions. Documented sources include case studies of logging equipment or systems published in trade journals or as monographs and timber appraisal data developed by the USDA Forest Service Region 1. This publication is essentially an update of Withycombe (1982).

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Johnson, Leonard R.; and John Fabricius.
Year: 1985
Title: Cost implications of managing a deck for a small straight tower yarder.
Source: Proceedings -- Improving mountain logging: planning, techniques, and hardware, May 8-11, 1985, Vancouver, BC; p. 101-106; Forest Research Institute of Canada, Vancouver, BC.

Pages: 6
Tables: 5
Figures: 4
References: 2
Prod. Data: Yes
Cost Data: Yes
Location: Idaho
Species:
Size: Gross volume per piece 93 board feet.
Terrain: Average slope 35%; range 20 to 60%.
Treatments: Clearcut, shelterwood
Operations: (04) Skyline yarding.
Products: Sawlogs

Remarks: A Koller Model K-300 yarder was operated on several small clearcuts and a shelterwood unit in Idaho. Operations demonstrated a significant problem in managing and controlling the yarder deck. Delay times were analyzed. A break-even approach was used to compare the cost of operations with these delays with the cost of using a hot-loader or swinging skidder to move material away from the deck.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Keegan, Charles E. III.
Year:	1981
Title:	The economic availability of forest residue in the Northern Rocky Moutains.
Source:	Proceedings -- Harvesting and utilization opportunities for forest residues in the Northern Rocky Mountains; Nov. 28-30, 1979; p. 55-63; USDA Forest Service, General Technical Report INT-110, Intermountain Forest and Range Experiment Station, Ogden, UT.
Pages:	9
Tables:	6
Figures:	0
References:	0
Prod. Data:	No
Cost Data:	Yes
Location:	Montana
Species:	
Size:	
Terrain:	
Treatments:	
Operations:	
Products:	Fuelwood, chipwood.
Remarks:	This paper analyzes the costs of harvesting and transporting forest residues to a manufacturing center in northwestern Montana. Volumes and types of available residues are also analyzed. Data sources are given in the text.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Kellogg, Loren D.; and Olsen, Eldon D.
Year:	1984
Title:	Increasing the productivity of a small yarder: crew size, skidder swinging, hot thinning.
Source:	Forest Research Lab, Research Bulletin 46, School of Forestry, Oregon State University, Corvallis, OR.
Pages:	44
Tables:	18
Figures:	6
References:	18, glossary, appendices.
Prod. Data:	Yes
Cost Data:	Yes
Location:	Oregon
Species:	Douglas-fir, grand fir.
Size:	Mean dbh 11 inches.
Terrain:	Slope range 9 to 38%.
Treatments:	Thinning
Operations:	(01) Chainsaw felling; (03) Skidder swinging; (04) Skyline yarding; (05) Chainsaw delimbing, topping, and bucking; (07)/(08) Self-loading log truck.
Products:	Sawlogs
Remarks:	Productivity of the Koller K-300 skyline yarder was evaluated in thinning operations. The effects of crew size, skidder swinging, and hot thinning were studied. Production and cost data for several studies are summarized for systems, functions, and cycle elements in relation to system, stand, and operational variables.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Kellogg, L. D.
Year:	1981
Title:	Machines and techniques for skyline yarding of smallwood.
Source:	Forest Research Lab, Research Bulletin 36, School of Forestry, Oregon State University, Corvallis, OR.
Pages:	15
Tables:	5
Figures:	6
References:	13
Prod. Data:	Yes
Cost Data:	Yes
Location:	Oregon
Species:	
Size:	Average dbh range 8 to 10 inches.
Terrain:	
Treatments:	Thinning
Operations:	(04) Skyline yarders
Products:	

Remarks: Research on skyline machines and techniques currently available for yarding smallwood is reviewed. Three categories of machines are discussed. Specific machines and techniques are reviewed with focus on thinning in young, dense stands. Multispan yarding as well as prebunching and swinging are considered. Study conditions and findings are summarized.

Yarders studied were the Skagit SJ series, various converted cranes, the Schield-Bantam, the Koller K-300, and numerous homemade machines. New low-cost yarders for smallwood are listed along with their cable capacities.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Kellogg, L. D.
Year:	1980
Title:	Thinning young timber stands in mountainous terrain.
Source:	Forest Research Lab, Research Bulletin 34, School of Forestry, Oregon State University, Corvallis, OR.
Pages:	19
Tables:	7
Figures:	9
References:	20
Prod. Data:	Yes
Cost Data:	Yes
Location:	Oregon
Species:	
Size:	Average dbh 10 to 14 inches.
Terrain:	Slope range 20 to 40%.
Treatments:	Thinning
Operations:	(01) Chainsaw felling; (03) Tractor skidding; (04) Skyline yarding, bunching winch; (05) Chainsaw delimbing, topping, and bucking.
Products:	Sawlogs
Remarks:	This paper discusses research findings from 1972 to 1979 on felling and bucking as well as yarding. Eleven studies are categorized into five areas -- felling and bucking, tractor skidding and skyline yarding, prebunch and swing yarding, multispan yarding, and the Igland-Jones Trailer Alp. Study conditions are presented and the findings are summarized.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Koch, Peter
Year:	1985
Title:	Utilization of Hardwoods Growing on Southern Pine Sites.
Source:	USDA, Forest Service, Agricultural Handbook No. 605, Volume II, Part IV, Chapter 16, p. 1428 - 1640, U.S. Government Printing Office, Washington, D.C.
Pages:	213
Tables:	50
Figures:	68
References:	376
Prod. Data:	Yes
Cost Data:	Yes
Location:	South
Species:	Hardwoods
Size:	Dbh range 4 to 16 inches
Terrain:	
Treatments:	
Operations:	(01) Chainsaw felling; (02) Feller-bunchers, stump and tree pullers, swathers, topwood harvesters; (03) Tracked and rubber-tired skidders (cable and grapple), forwarders; (04) High-lead and skyline yarders, aerial systems, bunching winches; (05) Chainsaw delimbing, topping, and bucking, manual piling; (06) Mechanical delimbers and buckers, merchandizers, whole-tree chippers; (07) Loaders; (08) Log trucks, chip vans, log yard and chip handling machinery.
Products:	Sawlogs, pulpwood, fuelwood, chips.
Remarks:	This is an exhaustive treatise on state-of-the-art systems for efficiently harvesting hardwood trees, transporting them to a mill, storing them, and merchandising them at stump or mill by segmenting boles, crowns, and roots to maximize tree value. Emphasis is on trees which are typically small in diameter, short, and crooked, growing in low-volume stands comprised of highly variable species mixes. Shortwood and longwood systems are described along with a wide array of specific equipment. Production and cost data for various operations is presented by function and (in some cases) by component activities and by dbh classes. References describing a few of the available system simulation models are listed. Other important discussions include factors affecting harvesting, ecological effects, residue salvage, and fuel requirements.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Koger, Jerry L.; and James R. Sherar.
Year:	1983
Title:	Analysis of the Taylor Skyliner in western North Carolina.
Source:	Jones, Earle P. Jr., Editor. Proceedings -- Second biennial southern silvicultural research conference, November 4-5, 1982, Atlanta, Georgia; USDA Forest Service, General Technical Report SE-24, p. 247-252, Southeastern Forest Experiment Station, Ashville, NC.
Pages:	6
Tables:	3
Figures:	4
References:	8
Prod. Data:	Yes
Cost Data:	Yes
Location:	North Carolina
Species:	Oak, yellow poplar, maple, hickory.
Size:	Mean dbh 10.0 inches, range 4.4 to 22.1 inches.
Terrain:	Steep, rocky.
Treatments:	
Operations:	(04) Cable yarding
Products:	Tree-length logs
Remarks:	Production rates, production costs, and operating characteristics of the Taylor Skyliner were determined for an 18-acre clearcut. Regression equations are presented for uphill yarding.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Lane, Richard A. Jr.
Year:	1981
Title:	An evaluation of operational harvesting techniques and systems applicable to the commercial thinning of southern pine plantations.
Source:	Thesis submitted to the Graduate Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, Va.
Pages:	140
Tables:	13
Figures:	17
References:	37, plus annotated bibliography
Prod. Data:	Yes
Cost Data:	Yes
Location:	South
Species:	Southern pines
Size:	
Terrain:	
Treatments:	Thinning
Operations:	(01) Chainsaw felling, hand bunching; (02) Feller-bunchers; (03) Animal and tractor skidding; (04) Cable yarding; (05) Chainsaw delimbing, topping, bucking; (06) Mechanical processing, chipping.
Products:	
Remarks:	This study investigated and analyzed operational factors affecting the efficiency and economics of thinning. Production and cost trends were quantified from computer simulation of two harvesting systems. Pertinent world-wide literature was summarized in an annotated bibliography.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Lanford, Bobby L.
Year: 1983
Title: Productivity and costs of the Timberjack 30 feller buncher.
Source: Forest Products Journal, Vol. 33, No. 1, January 1983, p. 62-66.

Pages: 5
Tables: 2
Figures: 3
References: 3
Prod. Data: Yes
Cost Data: Yes
Location: South
Species: Loblolly pine (plantation and natural)
Size: Mean dbh 6.1 inches; range 2 to 14 inches.
Terrain: Flat, dry
Treatments: Thinning
Operations: (02) Feller-buncher w/bunk accumulator
Products: Tree lengths

Remarks: Time and production studies were conducted on Timberjack Feller Buncher models TJ30 and RW30 in thinning plantations and natural stands of loblolly pine. (The model which limbs and tops was not time studied.) Factors such as tree size, load size, stand density, and brush were examined for influence on production rates. Only diameter at breast height and trees per acre significantly affected the productive time to fell and bunch trees. Cutting methods -- row only selection from both sides, and selection from one side -- were compared. A qualitative evaluation of the Timberjack 30 was also included.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Lanford, B. L.; and D. L. Siros.
Year:	1983
Title:	Drive-to-tree, rubber-tired feller-buncher production studies.
Source:	USDA Forest Service, General Technical Report SO-45, Southern Forest Experiment Station, New Orleans, Louisiana.
Pages:	14
Tables:	5
Figures:	1
References:	4
Prod. Data:	Yes
Cost Data:	No
Location:	South
Species:	Southern pines
Size:	Average Mean dbh 5.9. to 8.2 inches; range 3 to 14 inches.
Terrain:	
Treatments:	
Operations:	(02) Feller-bunchers with accumulators
Products:	
Remarks:	Reports cycle times by elements and productivity by dbh and stand density classes for four rubber-tired feller-bunchers on clearcut operations. Descriptions of forms and field procedures are given in an appendix.
	Machines evaluated were the Franklin 170XLN with Morbark 15-inch shear, John Deere 544 with Morbark 15-inch shear, John Deere 544 with Rome 20-inch shear, and Hydro AX 511 with Morbark 20-inch shear.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	LaPointe, Gerald B.
Year:	1984
Title:	Precommercial thinning in the Atlantic provinces.
Source:	Robertson, Doris, Proceedings Coordinator; and Julia White, Editorial Assistant. Proceedings -- Harvesting the South's small trees, April 18-20, 1983, Biloxi, Miss; Proceedings 7340, p. 49-57; Forest Products Research Society, Madison, Wisc.
Pages:	9
Tables:	3
Figures:	8
References:	10
Prod. Data:	No
Cost Data:	Yes
Location:	Eastern Canada
Species:	White birch, yellow birch, sugar maple, red maple, beech, jack pine.
Size:	Saplings
Terrain:	
Treatments:	Thinning
Operations:	(01) Brushsaw felling; (02) Mechanical choppers and cutters.
Products:	None
Remarks:	Precommercial thinning of dense, young stands in Canada's Atlantic provinces is described. Costs and spacing rate adjustment factors are given for manual operations. Mechanized equipment and studies are discussed.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: LeDoux, Chris B.; Roger D. Fight; and Tom L. Ortman.
Year: 1986
Title: Stump-to-truck cable logging cost equations for young-growth Douglas-fir.
Source: Western Journal of Applied Forestry, Vol 1, No. 1, January, 1986, p. 19-72, Society of American Foresters, Bethesda, Md.

Pages: 4
Tables: 2
Figures: 0
References: 19
Prod. Data: No
Cost Data: Yes
Location: Pacific Northwest
Species: Douglas-fir
Size: Dbh range 6 to 25 inches
Terrain: Slopes 10 to 50%, mountainous terrain.
Treatments: Thinning
Operations: (01) Chainsaw felling, (04) Cable yarders, (05) Chainsaw delimbing and bucking, (06) Log loading.
Products: Sawlogs

Remarks: Logging cost simulators and data from logging cost studies have been assembled and converted into a series of equations that can be used to estimate the cost of logging (thinning) young-growth coastal Douglas-fir in mountainous terrain of the Pacific Northwest. These equations were developed for two small cable yarders and one medium-sized yarder and are applicable for harvests of timber from 6 to 24 inches in diameter on slopes from 10 to 50%. Cost components can be easily calculated on a hand calculator. A computer program that can be adapted to many desktop computers and that will calculate the total stump-to-truck logging costs for a specified set of logging conditions is also available.

Yarders studied were the Koller K-300, the Ingland Jones Mini-Alp, and the Washington 078.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: LeDoux, Chris B.; and Lawson W. Starnes.
Year: 1986
Title: Cable logging production rate equations for thinning young-growth Douglas-fir.
Source: Forest Products Journal, Vol. 36, No. 5, May 1986, p. 21-24.

Pages: 4
Tables: 4
Figures: 1
References 14
Prod. Data: No
Cost Data: No
Location: Pacific Northwest
Species: Douglas-fir
Size:
Terrain:
Treatments: Thinning
Operations: (04) Cable Yarding
Products:

Remarks: A cable logging thinning simulation model and field study from cable thinning production studies have been assembled and converted into a set of simple equations. These equations can be used to estimate the hourly production rates of various cable thinning machines operating in the mountains of western Oregon and western Washington. The equations include seven small- and medium-sized cable yarders and are applicable to uphill thinnings of Douglas-fir from low to high volume removals. Hourly production rates can be easily calculated on a hand calculator using log size, volume removed per acre, and average yarding distance as inputs. These equations can be used to develop reasonable approximations of delay-free hourly production for several cable yarders operating in thinnings, under a variety of site and stand conditions.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Lynch, Dennis L.
Year:	1986
Title:	Production analysis of the Bitterroot yarder in Colorado.
Source:	Western Journal of Applied Forestry, Vol. 1, No. 1, January, 1986, p. 22-25, Society of American Foresters, Bethesda, Md.
Pages:	4
Tables:	3
Figures:	4
References:	2
Prod. Data:	Yes
Cost Data:	Yes
Location:	Colorado
Species:	Lodgepole pine (standing dead)
Size:	
Terrain:	Average slope 32 to 40%, range 17 to 57%; rocky.
Treatments:	
Operations:	(04) Skyline yarding
Products:	Fuelwood
Remarks:	The Bitterroot Miniyarder was analyzed for productivity during demonstrations on Colorado's Front Range. The yarder was operated in both single-span and multi-span configurations. Areas not accessible to ground skidding were logged. The yarder lost horsepower at higher elevations, which reduced its effectiveness.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Mandzak, John M.; Kelsey S. Milner; and John Host.
Year:	1983
Title:	Production and product recovery for complete tree utilization in the northern Rockies.
Source:	USDA Forest Service, Research Paper INT-306, Intermountain Forest and Range Experiment Station, Ogden, UT.
Pages:	17
Tables:	10, plus appendices
Figures:	10
References:	0
Prod. Data:	Yes
Cost Data:	No
Location:	Montana
Species:	Ponderosa pine, lodgepole pine, western larch, Douglas-fir.
Size:	Average dbh less than 9 inches.
Terrain:	Slope range 5 to 25%.
Treatments:	
Operations:	(02) Feller-bunchers; (03) Grapple-equipped rubber-tired skidders; (06) Tree processor; (07) Hydraulic log loader.
Products:	Sawlogs, chips.
Remarks:	A whole-tree harvesting system designed to produce logs and chips was evaluated on four sites, each with a different silvicultural prescription. Production rates for the overall system and for its various components were developed with time-motion study techniques. Variation in productivity between study areas was analyzed with respect to site characteristics.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Mansell, John S.
Year:	1985
Title:	Small crawler tractors and highlead towers log steep sensitive terrain.
Source:	Proceedings -- Improving moutain logging: planning, techniques, and hardware; May 8-11, 1985, Vancouver, BC; p. 109-111; Forest Engineering Research Institute of Canada, Vancouver, BC.
Pages:	3
Tables:	1
Figures:	0
References:	0
Prod. Data:	Yes
Cost Data:	Yes
Location:	British Columbia
Species:	
Size:	Dbh range 20 to 100 cm.
Terrain:	Maximum slope 40%.
Treatments:	
Operations:	(03) Tractor skidding; (04) Cable yarding.
Products:	Sawlogs
Remarks:	A procedure was developed to identify slopes that can be safely logged using ground skidding methods instead of marginally economical cable systems. Log production is compared.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Martin, James W.
Year:	1984
Title:	Implementing a plantation thinning harvesting system with a 5' 3" stick length restraint.
Source:	Robertson, Doris, Proceedings Coordinator; and Julia White, Editorial Assistant. Proceedings -- Harvesting the South's small trees, April 18-20, 1983, Biloxi, Miss; Proceedings 7340, p. 103-108; Forest Products Research Society, Madison, Wisc.
Pages:	6
Tables:	6
Figures:	1
References:	0
Prod. Data:	Yes
Cost Data:	Yes
Location:	Alabama
Species:	Southern pines (plantation)
Size:	
Terrain:	
Treatments:	Thinning
Operations:	(01) Chainsaw felling, (02) Feller-bunchers, (03) Rubber-tire skidders and forwarders, (04) Cable yarder, (05) Chainsaw delimbing and bucking, (06) Mechanical bucking, whole-tree chipping.
Products:	Pulpwood bolts, chips.
Remarks:	Reports production rates and costs for various machine systems used in plantation row thinnings. Feller-bunchers studied were a Timberjack 30 rear or side dumping corridor cutter, John Deere 555 crawler, Bobcat 1080, and Case Uni-loader 1845. Skidders and forwarders included John Deere 540B, Franklin 75, and Log Hog 760 rubber tire grapple skidders and a Gafner 4500F Iron Mule log-length forwarder. A Nordfor tilt winch and a bundle bucker were also studied.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Maus, F. J.; and H. L. Goetz.
Year:	1986
Title:	Full-tree thinning and chipping demonstration project.
Source:	Montana Forest and Conservation Experiment Station, University of Montana, Missoula, MT.
Pages:	69
Tables:	3, plus numerous in text.
Figures:	numerous un-numbered.
References:	0
Prod. Data:	Yes
Cost Data:	No
Location:	Montana
Species:	Lodgepole pine, ponderosa pine, western larch, Douglas-fir.
Size:	Average dbh range 2.7 to 5.1 inches.
Terrain:	Average slopes less than 20%.
Treatments:	Thinning
Operations:	(01) Chainsaw felling, hand bunching; (02) Feller-buncher; (03) Farm tractors w/grapples; (05) Chainsaw delimbing, topping, bucking; (06) Whole-tree chipper.
Products:	Hog fuel, posts, firewood, pulpwood.
Remarks:	Eight thinning units were used to demonstrate alternative methods of managing over-stocked precommercial timber stands with a minimal investment. The results of various prescriptions, production techniques, and equipment types and modifications are discussed. Included are detailed system descriptions, records of stand conditions, and production data for each phase of the operation. Yield and productivity is summarized in tabular form for four thinning prescriptions. This system enables the landowner to increase timberland productivity through thinning while producing saleable products to help defray thinning costs. (Also see Goetz 1987.)

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	McIntosh, J. A.; and J. Csizmazia.
Year:	1965
Title:	Harvesting lodgepole pine in the B.C. interior.
Source:	Canadian Forest Industries, June 1965.
Pages:	5
Tables:	2
Figures:	0
References:	7
Prod. Data:	Yes
Cost Data:	No
Location:	British Columbia
Species:	Lodgepole pine
Size:	Average dbh range 10.0 to 12.5 inches
Terrain:	Average slope range flat to 60%
Treatments:	
Operations:	(01) Chainsaw felling, (03) Crawler and rubber-tired skidders, (05) Chainsaw delimbing, topping and bucking, (06) Mechanical slasher.
Products:	Sawlogs
Remarks:	Studies the relationships of various factors (such as tree and stand characteristics, logging equipment, and logging techniques) to felling and skidding productivity on five operations. Reports average time breakdown by cycle components for each phase on each operation.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Murchison, H. Gary; and T. B. Tsay.
Year:	1972
Title:	An analysis of tree-falling time.
Source:	Department of Environment, Canadian Forestry Service, Internal Report FMR-23, Forest Management Institute, Ottawa, Ontario.
Pages:	14
Tables:	3
Figures:	0
References:	0
Prod. Data:	Yes
Cost Data:	No
Location:	Quebec
Species:	Black spruce, jack pine.
Size:	Mean dbh range 7.0 to 8.5 inches.
Terrain:	
Treatments:	
Operations:	(02) Mechanical felling, (03) Mechanical forwarding.
Products:	Tree lengths
Remarks:	A performance analysis of feller-skidders harvesting small black spruce and jack pine in Quebec. Tables show average times for various components of the stump-to-deck cycle for two types of feller-skidders mounted on articulated frame-steered chassis with articulated booms and shears and integral rear bunks.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Peters, Penn A.
Year:	1984
Title:	Steep slope clearcut harvesting with cable yarders.
Source:	Robertson, Doris, Proceedings Coordinator; and Julia White, Editorial Assistant. Proceedings -- Harvesting the South's small trees, April 18-20, 1983, Biloxi, Miss; Proceedings 7340, p. 69-78; Forest Products Research Society, Madison, Wisconsin.
Pages:	10
Tables:	6
Figures:	5
References:	6
Prod. Data:	No
Cost Data:	No
Location:	Eastern U.S.
Species:	
Size:	
Terrain:	
Treatments:	Clearcut
Operations:	(04) Cable yarding
Products:	Whole trees

Remarks: Presents a procedure to estimate yarding production and cost of cable yarding clearcuts on steep slopes. The procedure is applied to a Washington 78 yarding whole trees in the eastern U.S. Effects of harvest unit geometry and volume per acre on production and cost are discussed. Equations are based on a series of time and production studies conducted by the Forest Engineering Research Project in Morgantown, West Virginia.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Pierrot, Victor C.
Year:	1984
Title:	Thinning - manual or mechanical?
Source:	Robertson, Doris, Proceedings Coordinator; and Julia White, Editorial Assistant. Proceedings -- Harvesting the South's small trees, April 18-20, 1983, Biloxi, Miss; Proceedings 7340, p. 38-45; Forest Products Research Society, Madison, Wisconsin.
Pages:	8
Tables:	0
Figures:	12
References:	6
Prod. Data:	No
Cost Data:	No
Location:	
Species:	
Size:	Pole-sized
Terrain:	
Treatments:	Thinning
Operations:	(01) Chainsaw felling, (02) Feller-bunchers, (03) Grapple skidders.
Products:	Tree lengths
Remarks:	A general investigation of the relative advantages of mechanical vs. manual methods of thinning. Evaluates various mechanical systems with respect to the economic and silvicultural aspects.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Putnam, Nathan E.; Loren D. Kellogg; and Eldon D. Olsen.
Year:	1984
Title:	Production rates and costs of whole-tree, tree-length, and log-length skyline thinning.
Source:	Forest Products Journal, Vol. 34, No. 6, June 1984, p. 65-69, Forest Products Research Society, Madison, Wis.
Pages:	5
Tables:	2
Figures:	2
References:	9
Prod. Data:	Yes
Cost Data:	Yes
Location:	Oregon
Species:	Douglas-fir, grand fir, bigleaf maple.
Size:	Mean dbh 12.8 inches
Terrain:	Slopes to 50%
Treatments:	Thinning
Operations:	(01) Chainsaw felling, (03) Skidder swing, (04) Skyline yarding, (05) Chainsaw delimbing, topping, and bucking.
Products:	Sawlogs

Remarks: Production rates and costs were determined for harvesting smallwood by different methods of skyline yarding: whole tree (yarding with limbs and tops), tree-length (bucking done on the landing), and log-length (limbing, topping, and bucking done on the slope). A rubber-tired skidder was used to swing and sort the variously cut trees from the landing to a site on the haul road for further processing. The production rates for the felling and yarding cycles of each logging method were predicted from regression equations. Cost analysis indicated that, where feasible, cold decking (stacking in front of the yarder) of log-length material is the most cost effective method. Where cold decking is not feasible and a swing skidder is used, the whole-tree method is least expensive. Advantages of whole-tree and tree-length trucking are discussed.

Yarding equipment consisted of a 120 hp Schield Bantam T-350 mobile yarder with 1000 ft. of 3/4-inch skyline, a 28-ft. tower, and a Wyssen 2.5-ton load capacity carriage. A John Deere 440C rubber-tired skidder was used for swinging. The crew consisted of four people.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Sarles, Raymond L.; and William G. Luppold.
Year:	1986
Title:	Technoeconomic analysis of conventional logging systems operating from stump to landing.
Source:	USDA Forest Service, Research Paper NE-577, Northeastern Forest Experiment Station, Broomhall, Pa.
Pages:	23
Tables:	7
Figures:	6
References:	34
Prod. Data:	Yes
Cost Data:	Yes
Location:	Nationwide, Canada, New Zealand.
Species:	Various hardwood and softwood.
Size:	
Terrain:	
Treatments:	
Operations:	(01) Chainsaw felling; (02) Feller-bunchers; (03) Horses, minitractors, cable and grapple skidders; (04) Cable yarders; (05) Chainsaw delimbing, topping, bucking.
Products:	Sawlogs, tree lengths, whole trees.

Remarks: A technoeconomic analysis of timber harvesting systems was conducted to obtain key information for estimating longrun supply trends of roundwood materials from eastern woodlands. Productivity and cost factors for six stump-to-landing systems were developed from operational data for 47 harvesting operations. Tabular summaries compare stand conditions, treatments, production rates, and costs on a common basis. Technical factors and the effects of financial considerations were also assessed.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Sarles, Raymond L.
Year:	1985
Title:	Production and costs: chainsaw felling in hardwood thinnings.
Source:	Northern Logger and Timber Processor, August 1985, p. 24-25, 50, 56, 57.
Pages:	5
Tables:	2
Figures:	5
References:	3
Prod. Data:	Yes
Cost Data:	Yes
Location:	West Virginia
Species:	Allegheny Hardwoods
Size:	Average dbh 10 inches
Terrain:	
Treatments:	Thinning
Operations:	(01) Chainsaw felling, (05) Chainsaw delimbing, bucking, topping, and lopping.
Products:	Tree-length logs

Remarks: An analysis of cycle times, activities, delays, and tree measurement data for more than 900 trees in four stands. Includes a breakdown of productive times per tree for each activity for the average size tree as well as a breakdown of delay times per tree by reason for delay. Production rates are predicted for trees of various volumes based on distance between successively felled trees.

Also see Sarles 1984.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Sarles, R. L.
Year: 1985
Title: Thinning mountain hardwoods with a truck-mounted crane.
Source: Northern Journal of Applied Forestry, Vol. 2, No. 3, September 1985, p. 87-90, Society of American Foresters, Bethesda, Md.

Pages: 4
Tables: 1
Figures: 1
References: 13
Prod. Data: Yes
Cost Data: Yes
Location: Central Appalachians
Species: Cherry, maple.
Size: Pole timber and small sawtimber; Avg dbh 10 inches.
Terrain: Moderate
Treatments: Thinning
Operations: (04) Crane, jammer, skyline yarding.
Products:

Remarks: Analyzes use of truck-mounted crane for commercial thinning on moderate slopes of an overstocked stand of 60-year-old cherry-maple poletimber and sawtimber. Also compares production capabilities and costs of five small cable yarders as described in recently published literature. Yarders compared are a 1954 Bantam T-35, the Appalachian Thinner, the Koller K-300, the Bitterroot Miniyarder, and one unidentified skyline yarder.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Sarles, Raymond L.; Jeffery L. Wartluft; and Kenneth R. Whitenack.
Year:	1984
Title:	Chain-saw felling in hardwood thinnings.
Source:	Robertson, Doris, Proceedings Coordinator; and Julia White, Editorial Assistant. Proceedings -- Harvesting the South's small trees, April 18-20, 1983, Biloxi, Miss; Proceedings 7340, p. 58-65, Forest Products Research Society, Madison, Wis.
Pages:	8
Tables:	2
Figures:	4
References:	4
Prod. Data:	Yes
Cost Data:	No
Location:	West Virginia
Species:	Allegheny hardwoods
Size:	Average dbh 9 to 10 inches; range 5 to 11 inches.
Terrain:	Maximum slope range 25 to 55 percent.
Treatments:	Thinning
Operations:	(01) Chainsaw felling, (05) Chainsaw delimbing, bucking, topping, and lopping.
Products:	Tree lengths

Remarks: Production and efficiency rates were computed from time study and stem measurement data from four hardwood thinning operations in the central Appalachians. Hourly production rates were developed from a regression equation expressing productive felling time as a function of merchantable volume and distance between successively felled trees. Causes of delay time were analyzed. Average productive time per tree was computed and ranked by activity. Felling efficiency factors were applied to convert production rates to a scheduled hour basis.

With the results of this study, logging contractors and forest managers can convert cruise data for thinnings to estimate felling production rates. The estimates should prove helpful in predicting manpower and equipment needs and production costs.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Sarles, Raymond L.; and Kenneth R. Whitenack.
Year:	1984
Title:	Costs of logging thinnings and a clearcutting in Appalachia using a truck-mounted crane.
Source:	USDA Forest Service, Research Paper NE-545, Northeastern Forest Experiment Station, Broomhall, Pa.
Pages:	9
Tables:	9
Figures:	5
References:	9
Prod. Data:	Yes
Cost Data:	Yes
Location:	West Virginia
Species:	Allegheny hardwoods
Size:	Average mean dbh 6.2 inches; mean range 5.5 to 7.1 inches.
Terrain:	Flat to moderate
Treatments:	Thinning, clearcut
Operations:	(01) Chainsaw felling (04) Truck-mounted crane yarding.
Products:	Tree-length decks

Remarks: Four timber cutting treatments -- three levels of thinning and a clearcutting -- were applied on 60-year-old mountain stands of Allegheny hardwoods. The stands were logged by a three-man crew using chainsaws and a truck-mounted crane. Production rates were determined for tree-length logs decked at roadside. Work efficiency and productivity of the logging crew were somewhat higher on the thinning operations than on the clearcut.

Labor, equipment, and road construction costs were determined and applied to production rates. Comparison of logging costs among the four cutting treatments showed that the cost of wood decked at roadside was less for thinnings than for clearcutting. Silvicultural and environmental considerations of truck-crane logging are discussed.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Schiess, Peter; and Schuh, Donald
Year:	1985
Title:	Steep slope harvesting: the Kaiser Spyder feller-buncher.
Source:	Proceedings -- Improving mountain logging: planning, techniques, and hardware, May 8 to 11, 1985, Vancouver, BC; p. 133-138; Forest Engineering Research Institute of Canada, Vancouver, BC.
Pages:	6
Tables:	4
Figures:	5
References:	8
Prod. Data:	Yes
Cost Data:	No
Location:	Washington
Species:	Red alder, maple, Douglas-fir, western hemlock.
Size:	Average dbh range 8 to 19 cm.
Terrain:	Average slope range 35 to 55%; overall range 0 to 70%.
Treatments:	
Operations:	(02) Feller-buncher
Products:	Tree lengths

Remarks: The Kaiser X5M Spyder, a walking backhoe, was tested as a feller-buncher prototype for harvesting small diameter timber on slopes in excess of 30 percent. Basic interactions between the machine's felling-bunching rate and the timber stand, slope, and pertinent equipment factors were evaluated. Productivity averages were reported for cycle elements on six test sites. Felling and bunching time is displayed graphically by dbh classes.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Seymour, Robert S.; and Charles J. Gadzik.
Year:	1985
Title:	Commercial thinnings in small-diameter spruce-fir stands -- production and cost of skidding and skyline yarding, with and without prebunching.
Source:	Cooperative Forestry Research Unit, Research Bulletin 6, Maine Agricultural Experiment Station, Miscellaneous Report 309, College of Forestry Resources, University of Maine, Orono
Pages:	46
Tables:	10, plus appendix
Figures:	29
References:	38
Prod. Data:	Yes
Cost Data:	Yes
Location:	Maine
Species:	Spruce-fir: red spruce, balsam fir, white spruce, paper birch, northern white cedar.
Size:	Mean dbh 6.8 inches.
Terrain:	Moderate
Treatments:	Thinning
Operations:	(01) Chainsaw felling, (03) Radio-controlled winch, rubber-tired skidder, (04) Skyline yarder.
Products:	Tree-length sawlogs

Remarks: Three experimental systems for commercial thinning mature spruce-fir stands were compared. These involved prebunching with a Radio Horse winch followed by either skidding with a Franklin 120B cable skidder or by yarding with a Smith Timbermaster skyline yarder, as well as a conventional two-man skidder operation. Regression equations derived from time-study data, which predict total cycle time from winching or yarding distance and number of trees per turn, are presented. A general procedure for calculating costs per cord from the study results is described and used to compare the systems in terms of production and cost.

Skyline systems were more expensive than skidder operations. Prebunching improved skidding production dramatically but engendered only slight costs savings. The effect of varying tree size on total thinning cost is analyzed for each system; piece rates and stumpage values are presented for a range in tree size between 8 and 30 trees per cord.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Sirois, Donald L.; and Bryce J. Stokes.
Year: 1984
Title: Production and cost of the Makeri harvester.
Source: Robertson, Doris, Proceedings Coordinator; and Julia White, Editorial Assistant. Proceedings -- Harvesting the South's small trees, April 18-20, 1983, Biloxi, Miss; Proceedings 7340, 133-138, Forest Products Research Society, Madison, Wis.

Pages: 6
Tables: 4
Figures: 1
References: 1
Prod. Data: Yes
Cost Data: Yes
Location: Louisiana
Species: Loblolly pine (plantation)
Size: Average dbh 5.4 inches
Terrain:
Treatments: Thinning
Operations: (02) Mechanical felling, (06) Mechanical processing.
Products: Bolts 5 to 24 feet, tree lengths.

Remarks: The Makeri 33T, a small Finnish harvester, was evaluated during thinning of loblolly pine plantations in southern Louisiana. Production data was obtained to determine the effect of harvesting procedures and product length on production. Equations to estimate production and cost estimations were determined.

Also see Stokes 1983.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Staaf, K. A. G.; and Wiksten, N. A.
Year:	1984
Title:	Tree Harvesting Techniques.
Source:	Kluwer Academic Publishers, Hingham, MA.
Pages:	371
Tables:	15
Figures:	240
References:	127
Prod. Data:	Yes
Cost Data:	Yes
Location:	Sweeden
Species:	
Size:	
Terrain:	
Treatments:	
Operations:	(01) Chainsaw felling, manual bunching; (02) Mechanized felling and bunching; (03) Tractor skidding, forwarding, and bunching;(04) Bunching winches; (05) Chainsaw delimbing; topping, and bucking; (06) Mechanical delimbing, topping, and bucking, debarking and chipping; (07) Loaders; (08) Trucks.
Products:	Sawlogs, pulpwood, chips.

Remarks: This general textbook on tree harvesting includes discussions relevant to small timber and thinning operations. Techniques are applied in five basic harvesting methods. Performance of a machine system for thinning low volume of small trees is analyzed in detail. General summaries of production and cost information for different functions are presented in tables and 2-variable graphs. Some data is given for components of various functions or machine cycles.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Stokes, Bryce J.; and Bobby L. Lanford.
Year:	1986
Title:	Production and costs of manual delimbing, bucking, and piling in thinnings.
Source:	USDA Forest Service, Research Paper SO-223, Southern Forest Experiment Station, New Orleans, Louisiana.
Pages:	8
Tables:	12
Figures:	0
References:	6
Prod. Data:	Yes
Cost Data:	Yes
Location:	South Carolina, Mississippi, Louisiana, Alabama.
Species:	
Size:	Mean dbh 5.9 inches; mean range 5.5 to 6.9 inches.
Terrain:	Slope less than 5%.
Treatments:	Thinning
Operations:	(05) Chainsaw delimbing and bucking, hand piling.
Products:	Pulpwood bolts 5.25, 6.5, 7.5 ft.

Remarks: Studies were made of chainsaw delimbing and bucking with manual piling of bunched trees to determine productivity rates and costs for each function. Information was obtained from observations of six thinning operations in the South. Average dbh and bolt length significantly affected total delimbing and bucking time per tree. Manual piling time was dependent on average dbh and stems per bunch. Tables present elemental time per tree for various functions in each study unit as well as predicted production rates for various functions based on bolt length, dbh, and trees per bunch.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Stokes, Bryce J.; Jerry L. Koger; and Frank J. Pickle.
Year:	1983
Title:	Mor-Bell logger: skidding case study.
Source:	USDA Forest Service, Research Note SO-290, Southern Forest Experiment Station, New Orleans, La.
Pages:	4
Tables:	6
Figures:	1
References:	3
Prod. Data:	Yes
Cost Data:	Yes
Location:	South Carolina
Species:	Loblolly pine (plantation)
Size:	Mean dbh 5.6 inches; range 2.0 to 10.9 inches.
Terrain:	Moderate
Treatments:	Thinning
Operations:	(03) Grapple skidder, (06) Gate delimbing.
Products:	Tree-length decks

Remarks: A production equation was developed for the Mor-Bell logger for skidding while thinning a loblolly pine plantation. Production costs for skidding and iron gate delimbing were determined for a range of operating conditions. The ability to consolidate large bundles from small feller-buncher piles with minimal residual stand damage gave great flexibility to the feller-buncher operation.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Stokes, Bryce J.; and Donald L. Sirois.
Year: 1983
Title: Operational characteristics of a harvester in intermediate cuttings.
Source: Jones, Earle P. Jr., Editor. Proceedings -- Second biennnial southern silvicultural research conference, November 4-5, 1982, Atlanta, Georgia; USDA Forest Service, General Technical Report SE-24, p. 240-246, Southeastern Forest Experiment Station, Ashville, NC.

Pages: 7
Tables: 7
Figures: 4
References: 1
Prod. Data: Yes
Cost Data: No
Location: Louisiana
Species: Loblolly pine (plantation)
Size: Mean dbh 5.3 inches, range 2.8 to 9.8 inches.
Terrain: Moderate
Treatments: Thinning
Operations: (02) Mechanical felling, (06) Mechanical processing.
Products: Bolts 5 to 24 feet, tree lengths.

Remarks: The felling and processing capabilities of the Makeri 33T, a small Finnish harvester, were evaluated in a thinning operation. Cutting patterns tested were select thinnings with and without access corridors. The effect of product length on production was also evaluated. Regression analyses were used to establish production rates for the alternatives. Highest production was for tree-length products at close corridor spacings.

Also see Sirois 1984.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Sturos, J. A.; and M. A. Thompson
Year:	1986
Title:	Harvesting hardwood thinnings.
Source:	Sturos, John A., Complier. Proceedings -- Hardwood thinning opportunities in the lake states, April 20, 1984, Escanaba, Mich.; USDA Forest Service, General Technical Report NC-113, p. 31-53, North Central Forest Experiment Station, St. Paul, Minn.
Pages:	23
Tables:	11
Figures:	5
References:	4
Prod. Data:	Yes
Cost Data:	Yes
Location:	Lake States
Species:	Northern hardwoods: Red maple, sugar maple, American elm, black cherry, yellow birch, beech, red oak, aspen,balsam fir, spruce, hemlock, cedar.
Size:	Poletimber
Terrain:	Slopes 0 to 50%.
Treatments:	Thinning
Operations:	(01) Chainsaw felling, (02) Tracked and rubber-tired feller-bunchers, (03) Grapple skidders, forwarders, radio-controlled winch, (05) Chainsaw delimbing, bucking, and topping; (06) Slashers, chippers.
Products:	Chips, pulpwood, fuelwood, sawlogs.

Remarks: Five case studies of thinning hardwoods were done on gentle and difficult terrain. Methods ranged from fully mechanized whole-tree chipping operations to semimechanized, labor-intensive shortwood systems. Information is presented on the harvesting operations, equipment costs, and productivity.

Feller-bunchers studied were a John Deere 544 loader with an accumulating Rome grapple shear, a Drott 40LC, a Melroe Bobcat Model 1075 with 16-inch shear, a Timbco Hydro-Buncher Model 2518 with 18-inch shear mounted on a knuckle boom, and an Omark Hydro-Ax Model 311 with 16-inch shear. Skidders included a Clark 667 with grapple, a John Deere 740 with grapple, a Garrett Tree Farmer C5D with grapple, a John Deere 400 with chokers, and a John Deere 640 with grapple. A Radio Horse bunching winch and a Gafner Iron Mule Model 4501F shortwood forwarder were also evaluated. Whole-tree chippers included the Trelan D-60 and the Morbark 22-inch models. Fuelwood and pulpwood slashers, chainsaws, trucks, chip vans, and support equipment were also identified in the study.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Sturos, John A.; Robert M. Barron; Edwin S. Miyata; and Helmuth M. Steinhilb.
Year:	1983
Title:	The economics of a mechanized multiproduct harvesting system for stand conversion of northern hardwoods.
Source:	USDA Forest Service, Research Paper NC-237, North Central Forest Experiment Station, St. Paul, Minn.
Pages:	12
Tables:	14
Figures:	4
References:	10
Prod. Data:	No
Cost Data:	Yes
Location:	Michigan
Species:	Northern hardwoods
Size:	Dbh range 2 to 20 inches.
Terrain:	
Treatments:	
Operations:	(01) Chainsaw felling; (02) Feller-buncher; (03) Grapple skidder; (05) Chainsaw delimbing, topping, bucking; (06) Chain flail delimber, whole-tree chipper; (08) Chip trucker, chip vans.
Products:	Sawlogs, veneer logs, chips.
Remarks:	This study investigated the economics of clear-cutting a northern hardwood poletimber stand by a conventional whole-tree harvesting system and a sawtimber stand by several combinations of whole-tree chipping and log recovery. Data is based on time studies, but only costs are reported.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Tufts, Don M.
Year:	1984
Title:	The effect of tree size, stand size, and ownership on cost and productivity.
Source:	Robertson, Doris, Proceedings Coordinator; and Julia White, Editorial Assistant. Proceedings -- Harvesting the South's small trees, April 18-20, 1983, Biloxi, Miss; Proceedings 7340, p. 31-37; Forest Products Research Society, Madison, Wisconsin.
Pages:	7
Tables:	4
Figures:	0
References:	0
Prod. Data:	Yes
Cost Data:	Yes
Location:	Louisiana
Species:	
Size:	Dbh range 4 to 10 inches; average dbh 7 inches.
Terrain:	
Treatments:	
Operations:	(01) Chainsaw felling, (02) Feller bunchers, (03) Bob trucks, crawler tractors, grapple skidders, (05) Chainsaw delimbing and bucking, (06) Delimbing gate, tree harvesters, whole tree chipper, (07) Hydraulic loaders, (08) Log trucks, trailers, pallets, chip vans.
Products:	Pulpwood, chips.
Remarks:	A cost index is used to compare production and costs for eight different logging systems in harvesting small-sized timber. Stand size is discussed on the basis of access to the timber and the cost of moving equipment. Ownership problems are also discussed as they affect the cost and production of producing small timber. A wide variety of equipment was studied, but production data was combined for different makes of similar machines.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Watson, W. F.; B. J. Stokes; and I. W. Sarelle.
Year:	1986
Title:	Comparisons of two methods of harvesting biomass for energy.
Source:	Forest Products Journal, Vol. 36, No. 4, April 1986, p. 63-68.
Pages:	6
Tables:	9
Figures:	
References:	8
Prod. Data:	No
Cost Data:	Yes
Location:	Alabama, Mississippi.
Species:	Southern pines, hardwoods.
Size:	Dbh range 1 to 12 inches.
Terrain:	
Treatments:	
Operations:	(01) Chainsaw felling; (02) Feller-bunchers, directional shears; (03) Skidder; (05) Chainsaw delimbing, topping, bucking; (06) Iron gate delimber, whole-tree chipper; (07) Hydraulic loader.
Products:	Pulpwood (tree-length), chips.
Remarks:	Two harvesting methods for utilization of understory biomass were tested against a conventional harvesting method to determine relative costs. Costs per green ton are reported by function for plantation and natural study units.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Winsauer, Sharon A.; James A. Mattson; and Michael A. Thompson.
Year:	1984
Title:	Feller/bunchers in plantation thinnings: factors affecting productivity.
Source:	USDA Forest Service Research Paper NC-254, North Central Forest Experiment Station, St. Paul, Minn.
Pages:	15
Tables:	7
Figures:	10
References:	5
Prod. Data:	Yes
Cost Data:	No
Location:	North Central
Species:	Softwoods
Size:	Average dbh 4.0 inches, range 2.4 to 6.3 inches.
Terrain:	Flat
Treatments:	Thinning
Operations:	(02) Feller-bunchers
Products:	Tree-lengths
Remarks:	An analysis of various factors affecting feller-buncher productivity in thinning plantations based on computer simulation. Variables considered are stand characteristics, operational factors, and machine characteristics. Two basic feller-buncher designs were studied: chassis mounted and boom-mounted shear types.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Winsauer, Sharon A.; and Dennis P. Bradley.
Year: 1982
Title: A program and documentation for simulation of a rubber-tired feller-buncher.
Source: USDA Forest Service, Research Paper NC-212, North Central Forest Experiment Station, St. Paul, Minn.

Pages: 34
Tables: 6
Figures: 9
References: 5
Prod. Data: Yes
Cost Data: No
Location: North Central
Species:
Size:
Terrain:
Treatments:
Operations: (02) Feller-buncher
Products: Tree-lengths

Remarks: A computer simulation model designed for detailed study of the productivity and operation of a rubber-tired, frame-steered feller-buncher. It allows the user to determine cost and productivity under various stand and harvest conditions. Complete variable lists, program listings, and flow charts are included in appendices. Simulated productivity is corroborated by field data.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Withycombe, Richard P.
Year: 1982
Title: Estimating costs of collecting and transporting forest residues in the Northern Rocky Mountain region.
Source: USDA Forest Service, General Technical Report INT-81, Intermountain Forest and Range Experiment Station, Ogden, UT.

Pages: 12
Tables: 12
Figures: 2
References: 50
Prod. Data: Yes
Cost Data: Yes
Location: Northern Rockies
Species:
Size: Dbh range 4 to 28 inches; range of volume 0.5 to 100.0 cubic feet.
Terrain:
Treatments:
Operations: (01) Chainsaw felling; (02) Feller-bunchers; (03) Ground skidding; (04) Cable yarding; (05) Chainsaw delimbing; (06) Mechanical delimbing, whole-tree chipping; (07) Loading; (08) Hauling.
Products:

Remarks: A model is presented that determines cost per unit of harvesting wood residues. In deriving these costs such independent variables as skidding distance, volume per turn, and piece size are considered. Harvesting methods in the model include hand or mechanical felling, cable or ground skidding, chipping in woods, or roundwood logging.

Conversion factors and cost deflation factors are provided and, along with the independent variables, enable computation of residue harvest cost for a specific situation. Cost data are presented in a series of tables from which total costs can be summed.

Data sources include timber appraisal data developed by the Forest Service and the Bureau of Land Management, special studies of logging equipment or systems usually published as monographs, and case histories of specific operations reported in the various trade journals. When available, time estimates from various sources were converted to common units of measure and combined into a single time estimate.

This work has been updated and expanded (see Jackson 1984).

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Withycombe, Richard.
Year:	1981
Title:	Applications of a cost model to Northern Rocky Mountain residues
Source:	Proceedings -- Harvesting and utilization opportunities for forest resources in the Northern Rocky Mountains; Nov. 28-30, 1979; p. 45-54; USDA Forest Service, General Technical Report INT-110, Intermountain Forest and Range Experiment Station, Ogden, UT.
Pages:	10
Tables:	7
Figures:	2
References:	0
Prod. Data:	Yes
Cost Data:	Yes
Location:	Northern Rocky Mountains
Species:	
Size:	Dbh range 4 to 28 inches; volume per piece range 0.5 to 100.0 cubic feet.
Terrain:	
Treatments:	
Operations:	(01) Chainsaw felling; (02) Mechanical felling; (03) Ground skidding; (04) Cable yarding; (05) Chainsaw delimbing; (06) Chipping; (07) Loading; (08) Hauling.
Products:	Tree lengths, whole trees, chips.
Remarks:	See Withycombe 1982, Jackson 1984.

Appendix B

APPENDIX B

Bibliography for Future Review

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Ashmore, C.; B. J. Stokes; and B. L. Lanford.
Year: 1983
Title: Thinning performance of the Hydro-Ax 411 in fifth row removal.
Source: Paper No. 83-1604, American Society of Agricultural Engineers.

Pages: 19
Tables: 6
Figures: 6
References: 3
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Baumgras, J. E.; and C. B. LeDoux.
Year: 1986
Title: Costs of harvesting forest biomass on steep slopes with a small cable yarder: results from field trials and simulations.
Source: Smith, Wayne H. Editor; Biomass energy development; p. 133-142; Plenum Press, New York.

Pages:
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Bradley, Dennis P.; Frank E. Biltonen; and Sharon A. Winsauer.
Year: 1976
Title: A computer simulation of full-tree field chipping and trucking.
Source: USDA Forest Service, Research Paper NC-129, North Central Forest Experiment Station, St. Paul, Minn.

Pages: 14
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Cowdrick, R. M.; H. G. Gibson; and D. L. Cassens.
Year: 1982
Title: A systems analysis of selected mechanical harvesting equipment for thinning natural hardwood stands.
Source: Hill, R. F., Editor; Energy technology IX: energy efficiency in the eighties. Proceedings of the Ninth Energy Technology Conference; Feb. 16-18, 1982; p. 1374-1384; Washington, D. C.

Pages:
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks: Forest biomass, cost values.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Cubbage, F. W.
Year:	1981
Title:	Production and cost functions in southern pine harvesting.
Source:	Report No. 81-P-78, American Pulpwood Association.
Pages:	30
Tables:	
Figures:	
References:	
Prod. Data:	
Cost Data:	
Location:	
Species:	
Size:	
Terrain:	
Treatments:	
Operations:	
Products:	
Remarks:	

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Cubbage, F.
Year: 1981
Title: Are small-scale harvest systems cost competitive?
Source: American Society of Agricultural Engineers, Paper. St. Joseph, Michigan.

Pages:
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Curtin, D. T.; et al.
Year: 1980
Title: Biomass harvesting system test and demonstration.
Source: Technical Note No. B40, Tennessee Valley Authority.

Pages: 43
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Danielsson, B.
Year: 1983
Title: Harvesting and transportation of small, whole trees in Sweeden.
Source: Paper No. 83-1599, American Society of Agricultural Engineers.

Pages: 17
Tables: 6
Figures: 8
References: 7
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Fight, R. D.; C. B. LeDoux; and T. L. Ortman.
Year:	1984
Title:	Logging costs for management planning for young-growth coast Douglas-fir.
Source:	USDA Forest Service, General Technical Report PNW-176, Pacific Northwest Forest and Range Experiment Station, Portland, OR.
Pages:	10
Tables:	
Figures:	
References:	4
Prod. Data:	
Cost Data:	
Location:	Pacific Northwest
Species:	
Size:	
Terrain:	
Treatments:	
Operations:	
Products:	
Remarks:	

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Fisher, E. L.; D. L. Gochenour; and J. C. Biller.
Year: 1984
Title: Significant factors affecting performance of a Urus cable yarder.
Source: Transactions of the American Society of Agricultural Engineers, Vol.27, No. 4, p. 962-967.

Pages: 6
Tables:
Figures:
References: 2
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Fisher, E. L.; H. G. Gibson; and C. J. Biller.
Year: 1980
Title: Production and cost of a live skyline cable yarder tested in Appalachia.
Source: USDA Forest Service, Research Paper NE-465, Northeastern Forest Experiment Station, Broomall, Pa.

Pages: 8
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location: Virginia
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Gardner, Rulon B.
Year: 1980
Title: Skyline logging productivity under alternative harvesting prescriptions and levels of utilization in larch-fir stands.
Source: USDA Forest Service, Research Paper INT-247, Intermountain Forest and Range Experiment Station, Ogden, UT

Pages: 35
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location: Intermountain West
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Goetz, H. L.
Year:	1982
Title:	Timber thinning project for utilization of wood residue.
Source:	Montana Forest and Conservation Experiment Station, University of Montana, Missoula, MT.
Pages:	53
Tables:	
Figures:	
References:	
Prod. Data:	
Cost Data:	
Location:	
Species:	
Size:	
Terrain:	
Treatments:	
Operations:	
Products:	
Remarks:	

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Hoffman, B. F.
Year: 1982
Title: Skidding production and cost in softwood thinnings -- a wheeled skidder vs. farm tractor and winch.
Source: Life Sciences and Agricultural Experiment Station, Miscellaneous Report No. 264, p. 61-68, University of Maine, Orono, Maine.

Pages:
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location: Maine
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Huyler, N. K.; D. E. Koten; R. V. Lea; and A. P. Quadro.
Year: 1984
Title: Productivity and cost of three small fuelwood skidders.
Source: Journal of Forestry, Vol. 82, No. 11, Nov. 1984, p. 671-674, Society of American Foresters, Bethesda, Md.

Pages:
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Johnson, L. R.
Year: 1979
Title: Quanities and costs of wood biomass in Idaho.
Source: Bulletin No. 30; College of Forestry, Wildlife, and Range Sciences, University of Idaho, Moscow, ID.

Pages:
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Kasile, J. D.
Year: 1979
Title: Production and economics of whole-tree chippers.
Source: Frayer, W. E., Editor; Proceedings -- Forest resource inventories workshop; July 23-26, 1979; Colorado State University, Fort Collins, Colorado; p. 866-871.

Pages: 6
Tables:
Figures:
References: 1
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Keegan, Charles E. III; Timothy P. Jackson; Richard P. Withycombe; and Roland L. Barger.
Year: 1984
Title: Executive summary -- Site-specific assessment of wood residue utilization opportunities in the Libby, Montana, area.
Source: Bureau of Business and Economic Research, Division of Forest Products Research, University of Montana, Missoula, MT.

Pages: 35
Tables: 6
Figures: 9
References: 33
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Keegan, Charles E. III.
Year: 1981
Title: The cost and availability of forest residue in the northern Rocky Mountains.
Source: Bureau of Business and Economic Research, School of Business Administration, University of Montana, Missoula, MT.

Pages: 51
Tables: 16
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: LeDoux, C. B.
Year: 1985
Title: When is hardwood cable logging economical?
Source: Journal of Forestry, Vol. 83, No. 5, May 1985, p. 295-298, Society of American Foresters, Bethesda, Md.

Pages:
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: McMorland, B.
Year: 1985
Title: Production and performance of mechanical felling equipment on coastal B. C.: Timbco feller-buncher with Roto Saw head.
Source: Technical Note No. TN-85, Forest Engineering Research Institute of Canada, 201-2112 West Broadway, Vancouver, BC V6K 2C8, Canada.

Pages: 22
Tables:
Figures:
References: 3
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Miller, G. W.; and Sarles, R. L.
Year: 1986
Title: Costs, yields, and revenues associated with thinning and clearcutting 60-year-old cherry-maple stands.
Source: USDA Forest Service, Research Paper NE-582, Northeastern Forest Experiment Station, Broomall, Pa.

Pages: 8
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author:	Peters, P. A.; J. E. Baumgras.
Year:	1984
Title:	Production and cost analysis of the Bitterroot miniyarder in Appalachia.
Source:	Paper No. 84-1603, American Society of Agricultural Engineers.
Pages:	17
Tables:	1
Figures:	9
References:	4
Prod. Data:	
Cost Data:	
Location:	Northeast
Species:	
Size:	
Terrain:	
Treatments:	
Operations:	
Products:	
Remarks:	

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Post, I. L.
Year: 1983
Title: Two new systems for thinning hardwoods.
Source: Life Sciences and Agricultural Experiment Station, Miscellaneous Report No. 279, p. 28-34, University of Maine, Orono, Maine.

Pages:
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location: Maine
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks: Skyline-type cable system and a prebunching system. Includes management costs.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Post, I.L.
Year: 1983
Title: Two new systems for thinning hardwoods.
Source: Proceedings -- Hardwood forest management and utilization Symposium, Cooperative Forestry Research Unit, Information Report No. 6, p. 28-34, College of Forest Resources, University of Maine, Orono, Maine.

Pages:
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Rummer, R. B.
Year: 1983
Title: Analysis of the productivity, costs, and site impacts of a second generation small-log skidder.
Source: Forest Products Abstracts, Vol. 6, No. 11, p. 321-322. Thesis, College of Forestry, Wildlife, and Range Resources, University of Idaho, Moscow, ID 83843.

Pages:
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Schiess, Peter; Donald Schuh; Edwin S. Miyata; and Charles N. Mann.
Year: 1983
Title: Concept evaluation of a walking feller-buncher - the Kaiser X5M Spyder.
Source: Lynch, Dennis L., Coordinator and Editor. Proceedings -- Timber harvesting in the central Rockies: problems and opportunities; Jan. 4-6, 1983; Fort Collins, CO; p. 166-212; Publication No. XCM-87, Cooperative Extension Service, Colorado State University, Fort Collins, CO.

Pages: 53
Tables: 8
Figures: 8
References: 8
Prod. Data: Yes
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Schiess, Peter; and Keith Yonaka.
Year: 1983
Title: Bailing - a new concept in residue handling.
Source: Lynch, Dennis L., Coordinator and Editor. Proceedings -- Timber harvesting in the central Rockies: problems and opportunities; Jan 4-6, 1983; Fort Collins, CO; p. 214-240; Publication No. XCM-87, Cooperative Extension Service, Colorado State University, Fort Collins, CO.

Pages: 27
Tables: 3
Figures: 7
References: 22
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Schroering, J. D.; B. L. Lanford; and B. J. Stokes.
Year: 1985
Title: Franklin 105 feller-buncher: fifth-row thinning applications.
Source: Southern Journal of Applied Forestry, Vol. 9, No. 2, p. 110-113.

Pages: 4
Tables:
Figures:
References: 1
Prod. Data:
Cost Data:
Location: South
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Spradley, R.; and F. King.
Year: 1983
Title: Production study of a moderate to low-cost cable system.
Source: Annual Research Report -- School of Agriculture, Environmental Science, and Home Economics; Alabama Agricultural and Mechanical University.

Pages:
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location: Virginia, Arkansas
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks: Logging equipment tests in Virginia and Arkansas.

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Thompson, M. A.; and J. A. Sturos.
Year: 1984
Title: Bunching with low-investment systems in northern hardwood pole thinnings.
Source: Paper No. 84-1599, American Society of Agricultural Engineers.

Pages: 21
Tables:
Figures: 5
References: 16
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks:

LITERATURE REVIEW
Small Timber Harvesting: Production and Cost

Author: Whiting, W. A.
Year: 1983
Title: Analyzing stump-to-truck harvesting costs in small diameter southern pine plantations.
Source: Forest Products Abstracts, Vol. 6, No. 11, p. 325. Thesis, Dept. of Forestry, Mississippi State University, Mississippi, MS 39762.

Pages:
Tables:
Figures:
References:
Prod. Data:
Cost Data:
Location:
Species:
Size:
Terrain:
Treatments:
Operations:
Products:

Remarks: